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COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 45

Ground-water Resources of the Shenandoah Valley, Virginia

BY

R. C. CADY

With Analyses by E. W. Lohr

PREPARED IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

UNIVERSITY, VIRGINIA

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., March 3, 1936.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 45 of the Virginia Geological Survey series of reports the manuscript and illustrations of the *Ground-water Resources of the Shenandoah Valley, Virginia,* by Mr. R. C. Cady of the United States Geological Survey.

This report is one of a series being prepared in cooperation with the United States Geological Survey on the ground-water resources of Virginia. It discusses ground water in Augusta, Page, Rockbridge, Rockingham, Shenandoah, and Warren counties. Frederick County is not included because its ground-water resources have been discussed in Bulletin 41 of the Virginia Geological Survey.

In this report are summarized briefly the climate, geomorphology, and geology of the Shenandoah Valley. Discussed in some detail are the occurrence of ground water in relation to types of rocks and rock structure and the water-bearing properties of the rock formations underlying the Valley. Detailed data for each of the six counties are given in the latter half of the report.

As the amount and distribution of available ground-water supplies depend upon geologic conditions, and because of the great need of reliable comparative information by municipalities, industries, and property owners, this report is timely and should be of considerable interest and value.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, March 6, 1936.
RICHARD A. GILLIAM, *Executive Secretary and Treasurer.*

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Ground-water Resources of the Shenandoah Valley, Virginia

By R. C. Cady

ABSTRACT

The area discussed in this report consists of six counties—Shenandoah, Warren, Page, Rockingham, Augusta, and Rockbridge—of 3,546 square miles in area. It lies in the Shenandoah Valley, which is the long valley bounded on the east by the Blue Ridge and on the west by North Mountain, but also includes some of the more mountainous country to the west.

The area consists of three units which differ geologically and topographically. On the east is the Blue Ridge, which is at the north a single ridge but farther south in the area, a plateau. The Blue Ridge is composed of pre-Cambrian rocks, largely greenstone and granodiorite. The floor of the Shenandoah Valley is made up of sandstone, shale, and particularly limestone, chiefly of Cambrian and Ordovician age. These rocks have been folded into a complex syncline associated with minor anticlines and overthrust faults. The rocks west of North Mountain are sandstone and shale of Silurian and Devonian age, folded but less intensely deformed than the rocks of the Shenandoah Valley. Whereas most of the various kinds of rocks in the Shenandoah Valley are weathered and eroded at a uniform rate, west of North Mountain the very resistant Tuscarora quartzite and Pocono sandstone form mountain ridges which stand boldly above the lowlands developed on the less resistant Silurian and Devonian rocks. The rocks that constitute the Blue Ridge were pushed in many places toward the northwest on overthrust faults upon the younger rocks of the Shenandoah Valley. Similarly, the rocks of the Shenandoah Valley were pushed northwestward as a block, so that they overrode the still younger rocks that crop out west of North Mountain.

The water-bearing properties of the rocks that are exposed in the area are determined from the records of about 450 wells, and the chemical nature of the water is determined from the analyses of about 40 samples, taken from the various formations that crop out in different localities. The granodiorite and greenstone of pre-Cambrian age along the western flank of the Blue Ridge are found

to be capable of yielding 10 to 15 gallons a minute or less of excellent water through shallow wells. The basal quartzites of the Cambrian, being massive and hard, are regarded as poor sources of water, although no wells drilled into them are known in the area. The Tomstown dolomite is nearly as soluble as a pure limestone. However, it is probably because of its position along the foot of the Blue Ridge, where there is an active circulation of ground water that three wells obtain the largest yields in the area from it. Shallow wells have small yields. The water is comparatively soft. The Waynesboro formation yields moderate supplies from shallow wells. The water is fairly hard and high in iron. The limestones that range in age from middle Cambrian to middle Ordovician occupy the most populous central part of the Shenandoah Valley, and, being good water-bearing rocks, are of great economic importance. Most of the wells in these limestones yield less than 5 gallons a minute, since most wells have been drilled only to a slight depth in search of such a supply. Large supplies have been obtained from a few shallow wells and from some 1,000 to 2,000 feet deep. Not all deep wells, however, are successful. The water is hard and contains little mineral matter other than calcium bicarbonate. The Martinsburg shale is a dependable source of supplies of about 10 gallons a minute from wells of small or moderate depth. Few wells yield large supplies, and few dry wells are drilled. The water level stands fairly near the surface, even during periods of low rainfall. Water in the Martinsburg shale is harder than most limestone water, and may be locally high in iron and sulphur. Because the rocks of Silurian age crop out mostly in the immediate vicinity of mountain ridges, few, if any, wells derive their supplies from them. The Helderberg limestone yields, so far as the available records show, only small supplies through wells. Water from it is softer than water from most other limestones in the area. The Devonian sandstones and shales, from the Oriskany sandstone to the Catskill formation, are considered a hydrologic unit in this report. Shallow wells drilled into these rocks are almost certain to yield from 5 to 20 gallons a minute or less. Very few wells yield large supplies and few are failures. Water from these formations in most places is moderately hard and contains sodium bicarbonate and sulphate, with much or little iron and sulphur. No wells are known to derive their supply from the Pocono sandstone. The Recent and the Pleistocene (?) sediments are represented chiefly by the gravel that has been deposited along the foot of the Blue Ridge. Wells in this gravel, in favored localities, may yield small supplies, but many wells pass through

the gravel without finding water. The water in this gravel is likely to contain iron in objectionable quantity. Recent alluvium in certain stream valleys may be the source of rather large supplies of ground water.

Springs are fairly large and numerous in almost all parts of the area covered by this report. However, they are especially large and numerous in areas underlain by the limestones of Cambrian and Ordovician age. Thus the average rate of flow of 95 springs in these limestones is about 70 gallons a minute. The largest springs in the area of which the rate of flow is known are in limestone and alluvium. The springs with the smallest flow issue from quartzite. The water issuing as springs from the various rock formations resembles, in chemical content, the water taken from the same formation through wells, but spring waters are likely to be less highly mineralized than the comparable well waters. Springs are widely used as sources of household, industrial, and municipal water supplies, but they are less reliable than wells.

Twenty-two towns and cities receive their public supplies entirely or in part from wells or springs. About 26 per cent of the population of the whole area live in these communities.

INTRODUCTION

This report describes the ground-water conditions in Shenandoah, Warren, Page, Rockingham, Augusta, and Rockbridge counties. These counties lie chiefly in the Shenandoah Valley but also include an area west of the Valley. The combined area is 3,546 square miles.

This is the second geographic unit to be covered in a systematic investigation of the ground-water resources of Virginia undertaken as a result of a cooperative agreement between the Virginia Geological Survey and the United States Geological Survey. The first unit investigated consisted of the northern tier of counties in the State, comprising Arlington, Fairfax, Prince William, Loudoun, Clarke, and Frederick counties. A preliminary report on the ground-water resources of northern Virginia has been published as Bulletin 41 of the Virginia Geological Survey, and the complete report is expected to be published later. A general report on ground-water resources of the Coastal Plain province of Virginia was prepared by Samuel Sanford, through cooperation between the State and Federal Geological surveys, and was published in 1913 as Bulletin 5 of the State Geological Survey.

The present investigation was begun in September, 1932, under the direction of O. E. Meinzer, geologist in charge of the division of ground water in the United States Geological Survey, and field work was continued until November 1 of that year. In September, 1933, the writer spent about 2 weeks investigating the ground-water resources in Rockbridge County, which was not included in the original investigation. Records of about 450 wells and analyses of about 40 water samples constitute the principal data upon which the conclusions in this report are based.

The geologic map, with the structure sections (Pl. 1), was prepared by Charles Butts, of the United States Geological Survey, and has been published, with explanatory text, as Bulletin 42 of the Virginia Geological Survey.

The Shenandoah Valley is a geomorphic and geologic unit consisting of the lowland that lies between the Blue Ridge, on the southeast, and a range of hills referred to, for simplicity, as North Mountain on the northwest. The northern portion of Shenandoah Valley is split into two unequal parts by Massanutten Mountain, a major valley ridge that extends from the latitude of Strasburg to a point slightly southeast of Harrisonburg, a distance of about 45 miles. Some of the counties covered by this investigation include mountainous areas west of North Mountain. Much of the

rock in the Shenandoah Valley is limestone, and most of the remainder is shale. The limestone in particular has long been known as a reservoir of ground water, and wells are numerous in the area. In fact, most of the residents in the Shenandoah Valley and in areas west of North Mountain depend upon ground water for their supplies. The accessibility and importance of ground water, the uneasiness of users of ground-water supplies during the recent droughty years, and the progressive growth in industries and population of this part of the State have made a study of the ground-water resources very desirable. The present report is designed largely to answer the need of prospective users of ground water for information as to the possibilites of obtaining a supply of water in a certain area, or as to the most favorable locality in which to seek water of a given quality and quantity.

Records of wells were obtained from a few reliable drillers in the area. An effort was made to obtain the most accurate records rather than to obtain a large number of records. Most of the information was taken from the drillers' records and represents their total experience, successful and unsuccessful. Doubtless, part of the information is inaccurate in some of its detail. Most of the wells for which information is available were drilled in search of a small supply of water, and when this was obtained drilling ceased. Thus the maximum yield of the various rock formations may not be truly represented by the data here assembled. Moreover, it is not always possible to measure the maximum yield of well with whatever pumping device the driller may have at hand. With these facts in mind, the writer has summarized the information obtained and has interpreted it to the best of his ability on the basis of his studies of the structure, texture, and water-bearing properties of the rock formations.

The cooperation of the following drillers is acknowledged with appreciation: Turner Catlett, Strasburg; Charles F. Cole, of the Virginia Machinery & Well Co., Richmond; William Dawson, Staunton; W. J. Gochenour, Maurertown; J. T. Helbert, Broadway; W. H. Hicks, Waynesboro; H. N. Hulvey, Cross Keys, near Keezletown; John Rinker, Middletown; Fred Stickley, Strasburg; J. M. Totten & Son, Riverton; S. P. Totten, Lexington; and Grant & Wade Turner, New Market.

The water samples were collected by the writer in the spring of 1933 and were analyzed by E. W. Lohr in the water-resources laboratory of the United States Geological Survey.

CLIMATE

Virginia has a climate of modified continental type, which in its perfect development is characterized by a large range in temperature through the year and by a relatively high concentration of precipitation in the summer. Continental climate is likely to be variable, departing from normal by wide margins from year to year. The Shenandoah Valley is near enough to the Atlantic coast for the seasonal variations in temperature and precipitation to be smoothed out somewhat, without concealing the other characteristics of continental climate. Records kept at United States Weather Bureau stations in the lowlands of the Valley show that the climate is moist and the temperature equable. Thus the average annual temperature has been 53.4° Fahrenheit at Dale Enterprise, Rockingham County, during a period of 54 years of record and 54.8° at Staunton, Augusta County, during a period of 42 years. (See Table 2.) The average annual precipitation has been 34.17 inches at Woodstock, Shenandoah County, during a period of 42 years and 39.40 inches at Lexington, Rockbridge County, during a period of 65 years.

January is the coldest month in the Shenandoah Valley, having an average temperature of 33.1° to 35.4° at different stations. February is nearly as cold, but March is considerably warmer. July is the warmest month, the average monthly temperature at Woodstock being 74.7°, and at Dale Enterprise 73.7°. August is nearly as warm. The precipitation is normally more than twice as heavy in July or August as it is in November. Thus at Dale Enterprise the average rainfall in July is 4.92 inches, whereas in November it is 2.14 inches. The same relation holds at the other stations listed in Table 1.

The growing season in the valley—that is, the interval between the last killing frost in the spring and the first killing frost in the autumn—is normally between 6 and 7 months, extending from April to October or November. Frost is extremely local, however, and spots in low hollows may be visited by severe frost on many nights when hillsides are frost free.

The climate of the Shenandoah Valley has been slightly warmer and considerably drier during the past 20-year period from 1914 to 1933 than during the 45 preceding years of record. (See Table 3.) The accumulated excess of mean annual temperature above the average during this 20-year period is 7° and the accumulated deficiency of precipitation from the average is 75.80 inches. During the 20-year period from 1894 to 1913 the precipitation was

TABLE 1.—*Average monthly and annual precipitation at stations in Shenandoah Valley, in inches.*

STATION	Altitude (feet)	Years of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dale Enterprise	1,350	54	2.70	2.64	2.96	3.00	4.01	4.92	4.31	4.02	3.11	2.68	2.14	2.60	39.09
Lexington	1,060	65	3.23	2.96	3.31	3.03	3.52	3.90	3.93	3.87	3.34	2.88	2.55	2.88	39.40
Staunton	1,480	42	2.75	2.57	3.15	2.93	3.44	4.21	4.02	3.88	3.19	2.88	2.21	2.50	37.73
Woodstock	927	42	2.45	2.30	2.78	2.70	3.38	4.01	3.32	3.68	2.63	2.70	1.93	2.29	34.17

TABLE 2.—*Average monthly and annual air temperature at stations in Shenandoah Valley, in degrees Fahrenheit*

STATION	Altitude (feet)	Years of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dale Enterprise	1,350	54	33.1	34.5	43.0	52.4	62.4	70.0	73.7	71.9	66.6	55.3	43.8	35.0	53.4
Lexington	1,060	65	33.9	35.6	44.1	53.1	62.7	70.5	74.4	72.9	66.7	55.2	43.6	35.5	54.0
Staunton	1,480	42	35.4	35.7	44.8	53.5	63.5	70.6	74.3	73.0	67.6	56.0	45.4	37.1	54.8
Woodstock	927	42	33.5	34.0	44.3	52.8	63.3	70.1	74.7	73.0	67.7	56.3	44.9	36.1	54.2

TABLE 3.—*Annual precipitation at stations in the Shenandoah Valley, Virginia*
(In inches)

	Lexington	Dale Enterprise	Staunton	Woodstock
1869	40.00	....	32.37	....
1870	60.04	....	49.65	....
1871	39.43	....	39.02	....
1872	34.96	....	30.28	....
1873	44.41	....	....	....
1874	38.07	....	....	....
1875	37.94	....	....	....
1876	43.11	....	....	....
1877	42.40	....	....	....
1878	49.44	....	....	....
1879	38.30	....	....	....
1880	41.93	37.15	....	....
1881	33.82	37.73	....	....
1882	40.52	56.01	....	....
1883	32.20	37.42	....	....
1884	....	52.12	....	....
1885	35.11	48.10	....	....
1886	42.70	68.31	....	....
1887	....	46.12	....	....
1888	....	42.87	....	....
1889	54.86	52.54	....	....
1890	38.45	36.50	32.46	38.24
1891	42.41	40.52	42.24	42.65
1892	34.39	37.99	38.54	35.66
1893	42.56	40.80	44.01	35.17
1894	30.46	29.22	30.54	....
1895	31.16	29.50	37.77	....
1896	44.52	36.73	36.15	....
1897	37.60	32.99	41.98	39.36
1898	47.06	50.38	40.13	39.15
1899	42.34	31.99	36.97	31.54
1900	40.30	37.52	39.02	31.28
1901	50.56	56.28	51.18	44.37
1902	37.17	38.66	38.19	32.54
1903	42.76	42.26	45.63	35.98
1904	30.84	36.54	28.84	28.02
1905	40.01	39.17	36.26	37.45
1906	46.37	42.37	46.58	41.01
1907	48.10	43.10	41.60	36.27
1908	41.50	38.99	44.58	36.47
1909	35.72	30.93	37.16	32.04
1910	31.02	44.36	39.59	31.38
1911	37.71	36.95	42.57	39.49
1912	41.93	35.00	39.55	30.68
1913	42.09	44.61	43.65	34.90
1914	35.75	31.94	34.16	25.19
1915	43.81	39.00	35.98	34.93
1916	31.85	38.10	35.74	31.93
1917	30.23	31.62	34.03	29.77
1918	43.82	39.03	39.65	33.28
1919	41.54	33.32	37.80	34.29
1920	39.34	33.51	45.70	32.25
1921	29.68	28.72	32.10	27.27
1922	38.96	35.42	35.06	27.76
1923	32.23	31.02	30.19	27.29

TABLE 3.—*Annual precipitation at stations in the Shenandoah Valley, Virginia—Continued*
(In inches)

	Lexington	Dale Enterprise	Staunton	Woodstock
1924	44.10	42.00	....	42.37
1925	24.90	29.56	25.45	30.98
1926	39.84	44.76	40.40	39.45
1927	43.08	33.99	39.74	32.91
1928	36.27	34.12	38.48	34.19
1929	43.02	38.07	33.05	40.41
1930	20.85	17.60	16.76	16.43
1931	33.04	33.16	30.86	27.44
1932	42.08	42.02	40.12	43.87
1933	35.30	39.25	35.44	38.54

about average, but during the interval between 1913 and the beginning of the record in 1869 the precipitation was excessive. However, the accumulated deficiency of precipitation of the 20-year period from 1914 to 1933 is about equal to the accumulated excess of precipitation in the 45 years of previous record. (The annual precipitation at Lexington, the station with the longest record, for the years 1884, 1887, and 1888 is missing and the departures from the average precipitation at Dale Enterprise were substituted.)

A large accumulated deficiency of rainfall does not necessarily mean that the water table is correspondingly low. In the humid parts of the country the water table normally declines during the growing season, when evaporation and transpiration by plants of soil moisture and ground water are heavy. After the growing season the water table begins to rise as soon as the moisture that was extracted from the root zone has been replaced by percolating rain or snow water. If heavy rains occur in the autumn, winter, or early spring, the water table may be raised to such a height that natural drainage practically prevents further rise, regardless of any accumulated deficiency of precipitation. On the other hand, a severe drought or a period of dry years may cause marked depletion of the ground-water supply, as occurred in 1930-31, when many streams, wells, and springs failed.

A well in Arlington County near Washington, D. C., that has been under observation by the U. S. Geological Survey since 1928, showed a progressive yearly decline of the water level from 1928 to 1930. The highest point reached by the water level in 1929, after the recharge in the non-growing season that occurred, was not so high as it was in 1928. Moreover, the lowest point reached in 1929, at the end of the growing season, was lower than

in 1928. Both the highest and lowest water levels in 1930 were lower than in 1929. The precipitation at Washington, D. C., during the year 1931 was deficient, but the water level rose. In 1932 the water level rose higher than in 1931, and in 1933 it was still higher although the precipitation both in 1932 and 1933 was only moderately in excess of the normal.

GEOMORPHOLOGY

The area discussed in this report lies in the physical division of Virginia known as the "Valley and Ridge province." The limestones, shales, and sandstones of Paleozoic age that underlie the province were folded into synclines and anticlines, which subsequently were beveled by long-continued erosion to form a nearly level lowland. This lowland was then elevated in successive steps and was further eroded. The less resistant rocks, such as the shales and limestones, were the most extensively weathered and eroded and hence form the present valley areas. The more resistant rocks, such as the sandstones, were less weathered and eroded and hence form the present ridges. (See Pls. 2 and 3.)

During the erosion of the rocks of this province many of the stream courses became so modified by the differential wearing away of hard and soft rocks that they acquired linear patterns, but some streams in the area have not been thus modified. The main branch of the James River is remarkably unaffected by the presence of the Blue Ridge, for it has cut a gap through the hard rock as it cut its course down from the ancient featureless plain over which it originally flowed. The smaller tributaries of the James River and the main streams of the Shenandoah Valley show a greater or lesser dependence upon the structure of the underlying rocks.

The first ridges that rise to the northwest of the Shenandoah Valley and Massanutten Mountain owe their altitude to a caprock of resistant quartzite—the Tuscarora (Silurian). West of North Mountain the Devonian rocks crop out, and as most of them are shale and sandstone, less resistant to erosion and weathering than the Tuscarora quartzite, they underlie the small valleys of the region. The Pocono sandstone (Mississippian) is locally exposed in Rockingham County and, like the Tuscarora quartzite, is a ridge-forming rock. These resistant rocks are exposed in more places west of North Mountain than in the Shenandoah Valley, and hence the western area is the more mountainous.

It is clear that the topography of this province has undergone a complex history. At several times the earth's crust has remained stable long enough for the processes of weathering and erosion to reduce the region to a more or less flat plain, or peneplain. The streams rejuvenated by an uplift of the land then cut valleys into the old plain, and a new erosion cycle began. The periods of crustal stability and therefore of prolonged erosion have become shorter from the past to the present, and each erosion cycle and peneplain has been less complete than the first one, whose remnants are called

the Summit peneplain.[1] During the oldest erosion cycle a peneplain was developed by the streams in the whole Appalachian region, including the Piedmont province. The interstream divides were cut down largely to the common level, and hard as well as soft rocks were beveled. After a long time the whole region was uplifted with respect to sea level, and the streams became swifter and began to cut valleys into the old plain. When the uplift ceased, the streams cut down nearly to the baselevel of erosion and then began, by lateral planation, to remove the interstream divides. The second interval of stability was not long enough for the streams to destroy those portions of the old plain that were underlain by the more resistant rocks, and therefore the ridges of harder rock stood out above the newer plain. Remnants of the Summit peneplain consist of broad flats and gentle divides on the top of the Blue Ridge near Luray, certain other fragments near Waynesboro and the James River gorge, and parts of North Mountain that lie at an altitude of about 3,500 feet. Such peaks as Stony Man Mountain, in the Blue Ridge, must have stood out above the old plain by at least 500 feet. Still another uplift caused the dissection of the second or Upland peneplain, and it was almost completely destroyed except where it was preserved on more resistant rocks in the same manner as the Summit peneplain but at a lower altitude. Thus, rounded hills in the Blue Ridge north of Waynesboro at an altitude of 3,000 feet, other portions of the Blue Ridge near Front Royal at an altitude of 2,500 feet, and parts of the crest of North Mountain at appropriate altitudes are taken to be remnants of the Upland peneplain. A still lower surface, the Intermediate peneplain, was developed and later partly destroyed after crustal uplift. It is believed to be represented by certain spurs, knobs, foothill ridges, and low divides in the Blue Ridge and by wind gaps east of Massanutten Mountain at an altitude of 2,250 feet. During the next period of crustal quiescence the softer and more soluble rocks of the Shenandoah Valley were weathered and eroded into a broad, flat valley floor, and the Valley-floor peneplain may still be seen on the accordant summits of the low hills in the valley at altitudes of 1,800 to 2,000 feet on the headwaters of the Shenandoah and James rivers and at 600 feet near the Potomac River. Below these summits is a terrace, developed along the main streams during the last erosion cycle before the present one. The streams have cut below this terrace and are now engaged in widening and deepening their channels, a task which they will continue until there is another disturbance of the baselevel of stream erosion.

[1] Stose, G. W., Manganese deposits of the west foot of the Blue Ridge, Virginia: Virginia Geol. Survey Bull. 17, pp. 34-40, 1919.

Fort Valley in Massanutten Mountain. The broad valley has been eroded on Devonian shale. It is encircled by resistant Silurian sandstone. Photograph by Charles Butts.

A. Looking northwest across the Valley from a point on the Lee Highway about 5 miles northeast of Mt. Jackson. Little North Mountain first in distance; Great North Mountain beyond. Distance to Little North Mountain is 6 miles.

B. Athens limestone. Part of a very wide outcrop 3 miles northwest of Harrisonburg on the road to Green Mound Church. Looking northwest.

GEOLOGY

OUTLINE OF THE FORMATIONS

The part of the Shenandoah Valley and area to the west included in this report is occupied by sedimentary rocks of Paleozoic age cropping out in a rather complicated structural pattern. The rocks are mostly sandstone and quartzite, shale and mudstone, limestone and dolomite of various degrees of purity. Gravel of much more recent origin overlies the Paleozoic rocks in some areas, especially near the Blue Ridge. The rocks, which were originally deposited in large and extinct inland seas or on the shores of such seas, have been disturbed and deformed by earth forces that came into being at the end of the Paleozoic era. Because of this deformation the present outcrop area of the Paleozoic rocks is in general rather simple. The Shenandoah Valley, east of North Mountain, is underlain by rocks of early Paleozoic age, mostly limestone and shale, whereas west of North Mountain shale and sandstone of later Paleozoic age crop out. North Mountain divides the area into two rather distinct geologic, geomorphic, and ground-water provinces.

The general geologic and hydrologic characteristics of the formations in the area are summarized in Table 4. For a fuller discussion of the characteristics of the formations the reader is referred to a map and text by Charles Butts,[2] which form the basis of the following descriptions of the geology of the area covered by this report.

GEOLOGIC STRUCTURE

With respect to structure, the rocks in the area included in this report consists of three units—(1) the Blue Ridge overthrust sheet, which has overridden the younger rocks at the eastern border of the Valley; (2) the rocks of the Shenandoah Valley, mostly of Cambrian and Ordovician age, folded into a synclinorium and in turn comprising an overthrust sheet that overrides the younger rocks lying west of North Mountain; (3) the rocks of Silurian and Devonian age west of North Mountain, less intensely deformed than the other rocks.

The Blue Ridge overthrust sheet persists throughout the length of the area. The trace of the fault is irregular, partly because in some places the ancient rocks have resisted erosion better and partly because the fault plane has been folded. Thus near Front

[2] Butts, Charles, Geologic map of the Appalachian Valley of Virginia, with explanatory text: Virginia Geol. Survey Bull. 42, 1933.

TABLE 4.—*Geologic formations in the Shenandoah Valley, Virginia*

Age	Group and Formation	Thickness (feet)	Lithology	Water-Bearing Properties
Recent and Pleistocene (?)		Less than 1 to more than 100	Discordantly bedded clay, "ocher," silt, sand, and gravel. Boulders common. Material derived from ancient rocks of the Blue Ridge province, and from rocks in the Shenandoah Valley.	Water supplies generally not large, available in favored localities, but many wells pass through gravel into the underlying rock without encountering water. Iron is present in many places in sufficient concentration to render the water objectionable. Recent alluvium in certain stream valleys may be source of rather large supplies of water.
Mississippian	Pocono sandstone	350–1,700	Thick-bedded, non-marine, gray sandstone.	No wells known to derive their supply from the Pocono sandstone.
Upper Devonian	Catskill formation	500–2,000	Mostly red shale and red sandstone with some beds of gray and brownish rock.	Supplies of 5 to 20 gallons a minute or less available from wells of moderate depth. Large supplies rare, but few wells are failures. Some wells flow a slight amount at the surface, but in general artesian head is not strong enough to be of economic importance. Ground water is low in dissolved mineral content in some places and moderately high in others; moderately hard water with calcium bicarbonate, sodium bicarbonate and sulphate, with much or little iron and sulphur, is most common. Water may be corrosive in many localities.
	Chemung formation	2,000±	Greenish, poorly fissile mudrock with interspersed layers of medium-bedded sandstone.	
Middle Devonian	Brallier shale	2,000–4,000	Stiff, thinly laminated soft shale, with interspersed thin, even beds of fine-grained greenish sandstone.	
	Romney shale	500–1,000	Mostly fissile black shale, with some greenish shale and impure sandstone.	
	Oriskany sandstone	50– 150	Calcareous, thick-bedded, coarse-grained sandstone.	

Lower Devonian	Helderberg limestone	200– 500	Contains thick-bedded limestone and nodular, cherty impure limestone. Shale or sandstone replaces some of the limestone locally.	Scanty data indicate that small supplies are available from shallow to moderately deep wells. No large supplies known to be derived from these formations. One sample which was analyzed was softer than most other limestone waters.
Silurian	Cayuga group	500– 650	Thin-bedded limestone with beds of fissile red, green, and yellow shale, medium-bedded sandstone, gray or greenish mottled friable sandstone and shale, and thin-bedded dark-colored limestone.	
	Clinton formation and Tuscarora quartzite	150– 700	Extremely hard quartzite known locally as "flint," green shale and coarse-grained hard red and green sandstone.	Few wells; shallow and of small yield. Drilling in the quartzite difficult, expensive, and likely to be unfruitful.
Upper Ordovician	Juniata formation	300– 700	Red shale, mudrock, and sandstone for the most part but contains some gray sandstone.	No records of wells available.
	Oswego sandstone	100– 500	Thick-bedded greenish-gray, iron-speckled sandstone.	
Middle Ordovician	Martinsburg shale	1,500–3,000	Mostly dark colored calcareous shale, with some even-bedded green sandstone and more or less interbedded limestone. In parts of Rockbridge and Augusta counties the limestone is well developed in the lower parts of the shale.	Wells generally shallow, but some are about 200 feet in depth; average yield of wells recorded about 10 gallons a minute. Few large supplies may be expected, but few failures. Wells reported to withstand drought. Water level near ground surface in most places, and some wells flow slightly. Generally the water is highly mineralized and is harder than most limestone waters. Locally the water may be high in iron and sulphur.

TABLE 4.—*Geologic formations in the Shenandoah Valley, Virginia—Continued*

Age	Group and Formation	Thickness (feet)	Lithology	Water-Bearing Properties
Middle Ordovician	Chambersburg limestone	200– 400	Blue thin-bedded limestone, some layers nodular, but in places upper 50 feet consists of thick-bedded argillaceous limestone.	
	Lowville limestone	500–1,000	Dove-colored or blue limestone, partly thin bedded or shaly, but mostly medium thick bedded. Some mudrock.	
Lower Ordovician	Blount Group: Ottosee limestone	200– 400	Prevailingly thin-bedded to nodular limestone.	These limestones are probably the best sources of ground water in the area. Wells of small or moderate depth yield an average of a little over 10 gallons a minute. The greatest number yield less than 5 gallons a minute. A small proportion yield more than 20 gallons a minute. Large supplies have been obtained at considerable depths—as much as 1,000 to 2,000 feet—but not all deep wells encounter additional water at lower horizons. One deep well was a failure. A few shallow wells failed to encounter water, and others failed after continued use. Mud is frequently entered and has ruined some of the wells. Water is hard and contains little mineral matter other than that which causes the hardness.
	Blount Group: Athens shale	600–5,000±	Black fissile shale, passing to black thin-bedded compact conchoidal limestone, to pure or argillaceous bluish limestone, or to thick-bedded arkosic sandstone.	
	Blount Group: Holston limestone	200– 300	Thick-bedded coarsely crystalline light-gray to dark-gray limestone.	
	Stones River limestone	250–1,000	Dark to black medium coarse-grained limestone, commonly full of nodules of black chert, overlying pure compact or glassy limestone, generally light gray but in some places dark gray and thick bedded.	
	Beekmantown group	800–3,200	Cherty dolomite and limestone overlying thick-bedded gray medium-coarse cherty dolomite; at botton, thick-bedded limestone.	

Upper Cambrian	Conococheague limestone	1,200–2,000	Thick-bedded blue limestone, some dolomite, and beds of quartz sandstone with well-rounded grains. Siliceous or argillaceous, wavy laminae project upon weathered surfaces.	
	Elbrook dolomite	2,700–3,400	Ranges from thick-bedded medium-coarse pure dolomite to thinly laminated, finely crystalline light bluish-gray shaly dolomite. In upper part many beds 1 to 5 feet thick of pure light-gray limestone.	
Middle Cambrian ....?.......	Waynesboro formation	1,500–2,000	Consists largely of red mudrock and green shale but contains sandstone, limy, clayey beds, dolomite, and pure blue limestone in thin alternating beds.	Records of 4 shallow or moderately deep wells show yields from 16 to 23 gallons a minute. More data would probably show a lower average yield of wells in this formation. One sample that was analyzed was moderately hard and high in iron.
Lower Cambrian	Tomstown dolomite	1,500–2,000	Medium thick-bedded medium grained or coarsely crystalline bluish-gray to light-gray dolomite. Some thin-bedded limestone included.	2 shallow wells yield 10 and 20 gallons a minute; 3 deep wells yield from 500 to 700 gallons a minute each. These are the best wells in the area of which records are available. It is not known whether similar yields could be obtained at other points on the outcrop of this formation. One sample that was analyzed was low in dissolved solids and comparatively soft.
	Basal quartzites	4,800–5,200	Thick-bedded gray sandstones in some places thinner bedded and darker, gray siliceous shale with thin layers of sandstone; gray, thick-bedded sandstone above; coarse arkosic sandstone, some reddish, below; a little red shale and some conglomerate; quartz sandstone and arkose.	Hard, relatively impermeable rocks, not good sources of water. No information available in area included in this report.

TABLE 4—*Geologic formations in the Shenandoah Valley, Virginia*—*Continued*

Age	Group and Formation	Thickness (feet)	Lithology	Water-Bearing Properties
Pre-Cambrian			Granitic rock, much altered, south of Front Royal. Dense massive greenstone along most of the Blue Ridge.	Wells of moderate or small depth may obtain as much as 10 to 15 gallons a minute in the granitic rock, but less in the greenstone. No chemical analysis made of the waters, but in localities outside the area, water from the pre-Cambrian is low in mineral content.

Royal most of the Cambrian rocks have been overridden, whereas in other places the Lower Cambrian rocks are exposed. South of Stanley, in Page County, the fault trace follows the undulations of the Cambrian rocks, suggesting that the rocks and the fault plane have been folded slightly in a direction transverse to the main northeast-southwest structural trends. The fault is not exposed well in outcrops, but the rocks adjacent to it are greatly disturbed, and this may be at least a partial explanation of some of the exceptionally strong wells at certain points along the foot of the Blue Ridge.

A detailed description of the structure of the Cambrian and Ordovician rocks in the Shenandoah Valley proper would be tedious and useless, for the map shows it more eloquently than words. A brief outline, however, will serve to supplement the map and structure sections. The dominating structural feature in this unit is the Massanutten syncline, really a synclinorium. It extends from the northern end of the area studied almost to the southwest boundary of Augusta County. The axis of this synclinorium is slightly southeast of the median line of the Shenandoah Valley. Where the synclinorium is best developed—in the northeastern two-thirds of its length—its axis is occupied by rocks of Silurian and Devonian age, the Massanutten Mountain mass. Elsewhere the axis is occupied by Martinsburg shale. Between the Massanutten syncline and the Blue Ridge the rocks dip to the northwest, but small folds obscure this dip in some places. Between the Massanutten syncline and North Mountain the general dip of the rocks is southeastward, but minor structural features are better developed. For instance, a gentle anticline 2 miles northwest of the Valley Turnpike extends from the northern limit of the area studied to a point north of Harrisonburg. Conococheague limestone is exposed at its axis along much of its length. A syncline of about equal length and parallel to the anticline occurs near North Mountain, and Martinsburg shale occupies its axis. This syncline is complicated by a small thrust fault that cuts its axial region and brings its southeastern limb into juxtaposition with its northwestern limb northeast of Broadway. A smaller syncline southwest of the one just described extends from Harrisonburg to Middlebrook, Augusta County, and the Martinsburg shale occupies its axial area. This second syncline is offset to the southeast of the first. Near Burketown, on the boundary line between Rockingham and Augusta counties, a small mass of rock whose structural trend is not parallel to the trends of rocks nearby has been interpreted as a klippe, or an erosional remnant of an over-

thrust sheet that once overlay the area but has been destroyed by erosion. The North Mountain overthrust fault, which crops out from the northeast end of the area to the vicinity of Rockbridge Baths, in Rockbridge County, branches into two parts, one of which —the Staunton overthrust—trends toward the northeast along the middle of the Shenandoah Valley. These faults die out just south of New Market, near the boundary line between Shenandoah and Rockingham counties. Along its entire length the overthrust fault shows the effect of folding, indicating that movements along the fault took place while the rocks were being bent into folds. Rockbridge County is a structural entity, for most of the structural features that persist through Shenandoah, Rockingham, and Augusta counties die out in this county. The Blue Ridge overthrust fault extends into Rockbridge County, but the Massanutten syncline does not, and the North Mountain fault becomes indistinct. The Pulaski fault, however, begins in Rockbridge County and is continuous for many miles to the southwest but is not present in Augusta County nor other counties to the northeast. The Pulaski fault, in about the middle of the Shenandoah Valley, marks the line along which a long but gently folded syncline has been pushed to the northwest over the southeastern limb of another syncline, of which the Martinsburg shale forms the axis. Other folds occur in the middle part of Rockbridge County, but they are poorly developed except for a very sharp syncline between the Valley Turnpike and Rapps Mill, in the southwestern part of the county. Small thrust faults abound northwest of the Valley Turnpike, but their effect on the distribution of the rocks is slight. In the northern corner of the county a syncline in rocks of Devonian age plunges northeastward, and successively older rocks are exposed to the southwest. The Martinsburg shale is extensively exposed along the northwestern edge of the county, and in the southwest corner still older rocks crop out. Just beyond the northwestern boundary the rocks are involved in a rather well-developed anticline.

The above summary of the structure of the rocks in Rockbridge County leads directly to the description of the third structural unit, the area west of North Mountain. Here the folding of the rocks is less intense, and faulting is negligible. There are marked folds near the North Mountain fault, whose intensity is probably due in part to the effect of drag, or the pushing of the overriding overthrust mass upon the rocks beneath. Such a sharp fold is the anticline north and west of Singers Glen, Rockingham County. Back from the mountain the structural features are less

pronounced. The syncline east of Orkney Springs, in the Shenandoah Valley, is gentle, and the one to the northeast of it near Van Buren Furnace, is rather open. An anticline north of Fulks Run, Rockingham County, is also comparatively open. From Fulks Run to the southwest corner of Augusta County the structure is indistinct. Between Craigsville and Augusta Springs there is an anticlinal fold, and adjacent to the southeast, a shallow syncline. As the structure of the rocks is the all-important factor that determines the distribution of the various formations in the area it is well that the careful reader should understand the nature of these folds as they have been interpreted.

GEOLOGIC HISTORY

The geologic history of the area begins in the indefinite past, in pre-Cambrian time. The first incident of which a record has been detected was the outpouring of basaltic lava flows upon some unknown rock terrane. This basaltic lava cooled, hardened, and after an unknown interval was intruded by a granite-like rock, the hypersthene granodiorite of the Virginia State geologic map. After another immeasurable interval the rocks were subjected to great compressive earth stresses, so that they were changed in position and in composition and mineral structure. Erosion then removed great thicknesses of rock and left deep rocks exposed at the surface. Such was the condition at the beginning of the Paleozoic era.

The Cambrian period was ushered in by the encroachment upon the continent of a shallow inland sea. As the shore line moved over the land, the residual soil that had accumulated upon the ancient crystalline rocks and stream-deposited debris were reworked by waves and currents to form the basal quartzites, which are beach and near-shore deposits. The water continued to grow slowly deeper as the land subsided, so that the action of waves and currents was slight enough to allow the accumulation of limey ooze, which was later impregnated with magnesium carbonate and formed the Tomstown dolomite. From this time on through the Middle Ordovician epoch the geographic arrangement of land and sea was comparatively stable, although marked by numerous minor warpings, for most of the sediments that follow the Tomstown dolomite are shales and impure or pure limestones. During two intervals—namely, when the Athens and Martinsburg shales were being laid down—the inland sea was apparently partly cut off from the ocean, and black graptolitic shales were laid down in the comparatively quiet waters. Although the floor of the basin

had been subsiding slowly as the sediments were piled in, the basin appears to have become full after the deposition of the Martinsburg shale, for the Juniata formation, of uppermost Ordovician age, was partly a nonmarine sediment. Again in the Silurian period the subsidence of the sea bottom kept pace with the accumulation of sediments, for the Tuscarora quartzite, Clinton formation, and Cayuga group are marine. After the Lower Devonian Helderberg limestone had been deposited there was a gradual change in the character of the sediments. No considerable amount of limestone was deposited, but shale and sandstone became increasingly abundant, and in general the coarseness of the sediments increased as the Devonian period neared its end. The Catskill formation, of upper Devonian age, consists of nonmarine sandstone and shale.

At about this time the crust of the earth was again subject to some great change, and powerful compressive stresses were set up, acting in a northwesterly direction. The indurated sediments were folded, but while the folding was in progress the rocks of the Blue Ridge were broken along a flattish fault plane and pushed up over the younger Paleozoic sediments of the Shenandoah Valley. Meanwhile the rocks of the Valley region were themselves broken loose and pushed northwestward and upward over the still younger Silurian and Devonian rocks. At length the folding and faulting ceased, and the area was subjected to long periods of erosion punctuated by uplifts of the land.

Sometime in the recent past, probably in the Pleistocene epoch, the balance between the rate of erosion and weathering in the highlands and the rate at which rock debris could be cleared by streams from the lowlands was disturbed. Gravel, cobbles, sand, silt, and clay accumulated in the lowlands faster than it could be removed by the streams. It covered valleys and the small residual hills in the valley floors. The material is not now being deposited, and a considerable amount of it has been carried away by such streams as the Shenandoah and South rivers.

OCCURRENCE OF GROUND WATER IN RELATION TO ROCK STRUCTURE

Unconformities mark buried ancient land surfaces and imply the cessation of one period of sedimentation and the beginning of another, generally with an intervening period of erosion. There may or may not be a radical difference in the nature of the deposits in the two series of unconformable sedimentary rocks. Where there is not, the unconformity is of no particular interest in the discussion of ground water, but where there is, especially where there is a discordance in the dip of the two series of beds, the unconformity may exert considerable influence upon the movement and disposition of the ground water. For instance, along certain parts of the Blue Ridge where Lower Cambrian formations overlie the pre-Cambrian rocks in normal stratigraphic sequence, the younger rocks are fair or good sources of ground water, but the underlying ancient crystalline rocks probably are not. An unconformity may be marked by a weathered zone, and in such a zone fractures, solution channels, and decomposed rock may serve as good water-bearers. Valleys with alluvial fill in the buried land surface may also serve as excellent water conduits, whereas the ancient divides may be barren of water.

Anticlines, or up-folds in the beds of rock, affect the ground water in two important respects. First, if the anticlinal axis plunges, artesian head may be developed along the axis. (See Fig. 1.) Second, a good water-bearing formation may be brought to or near the surface along the axis of an anticline, whereas on the sides of the anticline this formation may be too deeply buried to be reached in drilling. The Cayuga group of formations, the Helderberg limestone, and the Oriskany sandstones of the area west of North Mountain are near the surface on limbs of anticlines, and they may be more promising sources of water supplies than the overlying Devonian shales and sandstones or the underlying Silurian formations. In the western part of Rockbridge County anticlinal folding has brought Cambrian and Ordovician limestones to and near the surface in a terrane characterized mostly by clastic rocks of Silurian and Devonian age that are likely to yield less water. A well may also tap the water-bearing bed at some point down the dip from the axis, and the water that has percolated from the outcrop down to the well may be less highly mineralized than the water farther away from the outcrop of that bed.

Synclines, or down-folds, are in general favorable to the development of artesian pressure, and if the water-bearing beds crop

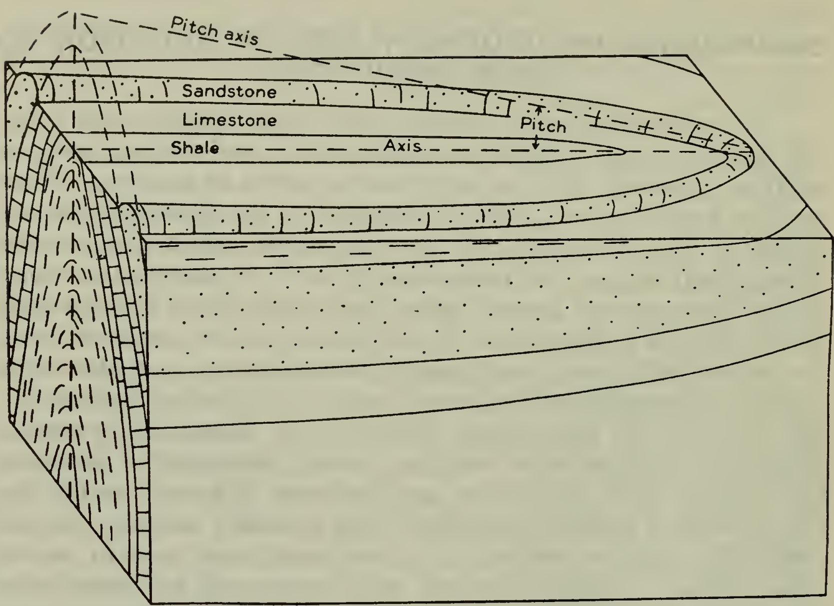

FIGURE 1.—Block diagram of an eroded pitching anticline. The beds of shale, limestone, and sandstone have been closely folded and beveled by streams and other agents. The weak rocks occupy a lowland surrounded by a ridge of resistant sandstone. The anticline pitches to the right, causing the outcrops of formations to disappear successively in that direction.

out in the limbs of the syncline at higher altitudes than the land surface nearer the axis, the conditions are favorable for obtaining flowing wells. (See Fig. 2.) On the other hand, a syncline may carry a water-bearing bed to so great a depth as to make it unavailable for wells near the axis of the fold. If water percolates into the outcrop of a water-bearing bed at a high level on one side of a syncline, it may be carried down the dip of the bed to a great depth, heated as a result of the high temperature of the rock at that depth, and thence carried up by artesian pressure to the opposite side, where it may be discharged as a warm spring at a lower level than the outcrop. The warm springs in the Shenandoah Valley and west of it are, according to Reeves,[3] due to this condition. Water circulating down the dip of a limestone bed in one limb of a syncline and passing up the other limb, may dissolve channels in the limestone bed so that wells may encounter large supplies of water at great depth. It is believed that this process has taken place in the northern and central parts of the Shenan-

[3] Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, pp. 28-35, 1932.

doah Valley, especially where the folds are strongly developed and where the axial region of the syncline is occupied by Martinsburg shale.

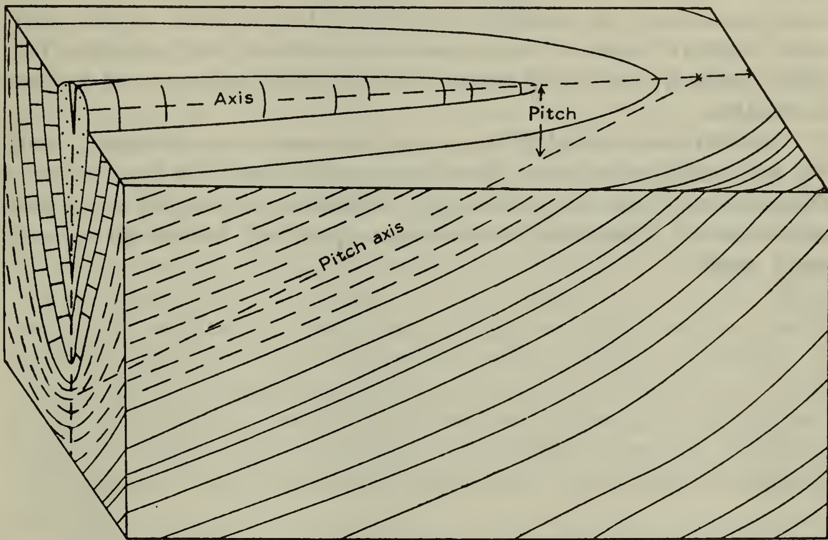

FIGURE 2.—Block diagram of an eroded pitching syncline. (Compare with Fig. 1.) The resistant sandstone forms a ridge in the lowland eroded on the surrounding weaker limestone and shale.

Faults, or displacements of the rocks along fissures, may act in any of three ways to modify the disposition of ground water. A fault fissure may act as a conduit, especially if the rock which it cuts is brittle. Thus warm water or even hot water may be brought to the surface along faults from great depth. If the fault fissure is filled with gouge it may act as an underground dam to store ground water on the upstream side, or the water may be dammed if the broken edge of the water-bearing bed is brought next to an impermeable bed by the faulting. A fault may displace a water-bearing bed, so that it may be encountered in drilling at either a higher or a lower level than where it is expected, or the fault may cut out the bed entirely at the well site, or cause the bed to be encountered twice in the same well. In the Shenandoah Valley faulting has taken place on a large scale, but the faults themselves are not numerous, and so far as known there are no local examples of the effect of faults upon ground water.

Joints, fissures, and bedding planes may be efficient conduits for water, especially if they are near enough to the surface to be

enlarged by weathering and solution. Joints and fissures are likely to decrease in size and number with depth, but bedding planes may remain channelways even at considerable depths. In beds of soluble rock, such as limestone, the structural features mentioned may be enlarged greatly by the solution of the walls, and a great maze of interconnected tunnels and galleries may carry large quantities of water, forming true underground streams and lakes.

In the Shenandoah Valley artesian pressure is exhibited chiefly by wells drilled into the Martinsburg shale and the formations of Middle and Upper Devonian age. However, few of the wells flow, and most of those that flow must be pumped, for the pressure is very slight.

OCCURRENCE OF GROUND WATER IN RELATION TO THE PRINCIPAL TYPES OF ROCKS

IGNEOUS ROCKS

Granite and other intrusive igneous rocks do not contain interconnected pore spaces through which water may pass, but they generally contain joints in two or more intersecting sets and in some places shear zones and faults. The joints are attacked by weathering and solution and consequently are most open near the surface. Generally joints become less numerous and less open with depth. Water in economic quantities is generally found in the joints but the likelihood of obtaining a water supply from these rocks at depths of more than a few hundred feet is small. Shear zones and faults may yield water freely, and they extend deeper than the joints, but they are present only in certain localities. A zone of porous weathered rock occurs near the surface in many places underlain by granitic rocks and is generally promising as a source of water. In many deep wells drilled in granite rocks the chief supply of water probably comes from the surficial weathered material.

Rocks formed of extrusive lava are extensively jointed and contain flow breccia, lava tunnels, and other large openings which are excellent water conduits and make these rocks superior water-bearers. In the course of time these openings are generally obliterated by weathering, pressure, recrystallization, and other agencies, and hence ancient lava rocks, such as the Catoctin greenstone, though originally doubtless excellent water-bearing formations, have become very unproductive.

METAMORPHIC ROCKS

Contact metamorphism, whereby new material has been introduced into a rock, is usually detrimental to that rock's water capacity, because not only are its pore spaces filled with the new material, but replacement may destroy the openings that might serve as channelways for water.

Regional metamorphism may increase the capacity of a rock for water, especially where a shale or an igneous rock is compressed into a schist. The incipient fracture planes thus developed may become enlarged by weathering, so that rather large quantities of water may move through or be stored in them. A schist is usually fairly soft and easy to drill. A slate behaves very similarly to a schist, in that the slaty cleavage provides excellent spaces for

water when the cleavage planes are once opened up. A gneiss is not usually different from a granite in its water-bearing properties. When a limestone is changed into a marble the joints and solution channels are likely to be closed, but new openings of the same kind may later be developed in the marble. A quartzite is a very poor water-bearer unless it is fractured, and even then it may remain a poor source of water because its relative insolubility prevents much enlargement of its fractures by solution. It is also hard to drill.

SEDIMENTARY ROCKS

The clastic rocks, such as gravel, conglomerate, sand, sandstone, silt, clay, and shale and their derivatives of mixed types, differ from one another in their water-bearing properties. Clean gravel, such as some of that encountered locally in valley alluvium, is one of the best of water-bearing beds. Much gravel, however, has a matrix of silt or sand that diminishes its permeability to a greater or lesser extent. This is true of the Pleistocene (?) gravel of the Shenandoah Valley, in which pebbles and cobbles are embedded in silt and clay. Conglomerate is generally a poorer source of water than gravel, owing to the cementation of the matrix. In cemented conglomerate the water must percolate through fractures, which may be rare.

A well-sorted sand usually yields large quantities of water. Sandstone, if the sand was clean and well sorted and has not been cemented too much, is also an excellent water-bearer. Much sandstone is jointed and bedded, and in such rock the joints and bedding planes add considerably to the space available for water. However, the Cambrian, Ordovician, Silurian, and Devonian sandstones in the Shenandoah Valley and area west of North Mountain are only moderately good water-bearers, because of the high degree of cementation, or poor sorting, or both. Much of the Devonian sandstone contains silt, which not only reduces the number of large pore spaces but also makes the rock less brittle and hence less likely to fracture and produce joints under stress.

Clay is a poor source of water because it consists of particles that are so small that the pore spaces between them hold the water by molecular attraction. The claylike material encountered by wells in some cavities in the limestone in the Shenandoah Valley and the clay beds in the Pleistocene (?) gravel yield practically no water. If the clay has become hardened into a shale, bedding planes, shaly partings, and joints may be numerous and more or less uniformly disturbed, so that most shales are to be

considered reliable sources of small water supplies. The Martinsburg shale is an example. Shallow wells in shale tend to survive drought better than similar wells in most other types of rock. The water in the shales in the Shenandoah Valley and areas west of North Mountain is usually rather highly mineralized. Mudstones like those in the Catskill formation, somewhat similar to shale lithologically but lacking the shaly partings, are usually less productive of water.

Limestone is an erratic source of water. Its joints and bedding planes are enlarged by solution by water charged with carbon dioxide, probably above or immediately below the water table except in unusual circumstances. When the solution channels become sufficiently widened, the water behaves like that in a surface stream. Where a large channel or underground stream is encountered by a well, an almost inexhaustible supply of water may be obtained. If a well misses the channels a dry hole may result. Many of the channelways become filled with mud, and a well drilled into one of these mud-filled channelways may be a failure unless the mud can be cased off. The behavior of limestone wells during a drought often causes considerable difficulty, because they may go dry with no warning in the nature of a gradual diminution of yield, and because the water table in most limestones fluctuates widely over periods of excessive and deficient rainfall. The water from limestone wells is usually hard, and it is also liable to pollution owing to the ease and rapidity with which the water moves through the rock and the lack of natural filtration.

A limestone terrane, such as parts of the Shenandoah Valley, represents a very large reservoir for ground water. Much of the rain that falls sinks rapidly into the solution channels, and some large areas underlain by limestone have no surface drainage except during excessively rainy periods. The area in Clarke County east of Opequon Creek, immediately north of the area covered by this report, has no perennial surface drainage. Although wells are likely to encounter difficulty locally, the limestone is the best source of water in the area, and probably in most places attempts to obtain even a large supply will be successful.

RECOVERY OF GROUND WATER

DRILLED WELLS

Most of the usable ground water in the Shenandoah Valley and the area west of North Mountain occurs in the sandstone, shale, or limestone, and wells drilled by the solid-tool method afford the most practicable means of extracting it. There are very few localities where, according to the data available, persistent efforts to obtain water by drilling have been unsuccessful. The rocks are not very hard, and aside from a few mechanical difficulties, drilling is comparatively cheap and easy. Deflection of the bit along tilted beds of rock, and the presence of open and mud-filled caverns are the chief sources of trouble, but none of these are insurmountable for the skilled driller. Furthermore, the thinness of the residual soil on the bedrock and the absence of any extensive and thick unconsolidated water-bearing sediments make it unnecessary to case the wells very deep, and screens are seldom needed.

DUG WELLS

Dug wells are cheaper than drilled wells, chiefly because they are not so deep. They are ordinarily of large diameter, and for that reason they are easy to clean out and repair. However, to case them securely against contamination by surface water is difficult, and the water-bearing soils and alluvium into which wells can be dug easily is rather thin in most parts of the Shenandoah Valley and the area west of North Mountain. The topographic relief is rather large in most parts of the area, and the texture of much of the bedrock is open enough for the water table to fluctuate through a considerable vertical range in response to deficient or abundant rainfall. Thus dug wells are likely to go dry in droughts, and if they are dug to bedrock it may be impossible to deepen them enough to reach water. For these reasons dug wells are not widely used except in part of Rockbridge County, and they are not recommended except where the local conditions are especially favorable.

Springs.—Springs are both numerous and comparatively large in the Shenandoah Valley and the area west of North Mountain. They are widely used, and many of them are very satisfactory. No source of water is less expensive than a spring whose discharge can be piped by gravity to the point where the water is used. Moreover, spring water is almost certain to be less highly mineralized than well water from the same rock formation. On the other

hand, many springs go dry in droughts and become muddy during periods of heavy rain. It is more difficult to protect springs from contamination by surface water than drilled wells. If they are carefully guarded, however, many springs are entirely satisfactory as sources of private and public water supplies.

INFILTRATION GALLERIES AND GROUND-WATER DAMS

An infiltration gallery is essentially a well dug horizontally through a water-bearing bed for the purpose of intersecting and conducting away the ground water that flows into it. Infiltration galleries are most economical in places where ground water will flow into them under natural head. In most parts of the area studied conditions are not favorable for the use of galleries. The municipal supply for Strasburg, Shenandoah County, is collected in a stream valley on the east side of Massanutten Mountain. The water is conducted through a tunnel to the west side of the mountain by gravity, and thence it is piped down to the town. This tunnel, it was hoped at the time its construction was proposed, would serve as an infiltration gallery as well as a conduit. It was found, however, that no appreciable quantity of ground water was added to the surface water flowing through it. (See pp. 60-61.)

Ground-water dams are not as useful for storing water as surface-water dams, but they may serve to collect the ground water that percolates through a water-bearing material, as through the alluvium of a stream valley. A ground-water dam has been constructed in the valley of the Dry River, in Rockingham County, to divert the underflow into the intake of the water-supply system of the city of Harrisonburg. (See pp. 88-89.) Although it has very little storage capacity, it supplements the surface-water supply at low stages of the stream by recovering the water that is percolating down stream during these periods of low water. Such a dam is rather simple and inexpensive as compared with a surface-water dam. It is probable that in other valleys in the mountainous parts of the area ground-water dams could be successfully used to collect ground water.

WATER-BEARING PROPERTIES OF THE ROCK FORMATIONS

PRE-CAMBRIAN ROCKS

Records of five wells drilled into pre-Cambrian rocks in Warren County provide the data for this discussion. All of these wells are in altered granite-like rock that makes up a small part of the Blue Ridge Mountain mass. As the pre-Cambrian rocks are confined to the spurs and foothills of the Blue Ridge, they are not of great importance as a source of water supply.

This granite-like rock (hypersthene granodiorite and its altered derivatives) is practically impermeable, for its crystals interlock and intermesh, except where it is broken by crevices such as joints and shear zones. Therefore the productivity of a well in this rock depends entirely upon the size and the number of openings it encounters. The crevices capable of yielding water are most numerous and largest near the ground surface, where the agencies of weathering have long been active, and consequently wells drilled below the zone of active weathering have increasingly poorer chance of encountering large supplies of water. None of the five wells are more than 80 feet deep. The average depth is about 60 feet, and the average yield, as estimated by the driller, is 14 gallons a minute. From observations on wells in similar rocks elsewhere it appears that these wells are exceptionally strong, probably because the rock is more broken than is usual for such rocks, owing to its nearness to the overthrust fault zone at the foot of the mountain.

In most other places along the western slope of the Blue Ridge the bedrock is greenstone, a hard, tough altered basalt in which openings are small and few. The greenstone in the northern part of the Piedmont province is an extremely poor source of water.

BASAL QUARTZITES OF THE CAMBRIAN SYSTEM

The basal Cambrian quartzites crop out along the western foot of the Blue Ridge from Warren County through Rockbridge, with only one interruption, near Waynesboro. These rocks in the main dip steeply westward. They are hard and relatively impermeable except as they are jointed and shattered. No records of wells in these quartzites are available in the area studied, but information obtained from wells outside the area indicates that they are not good sources of water. Drilling in them is difficult and expensive, and the wells are unlikely to yield much water. A few

wells in these rocks in Clarke and Loudoun counties, however, are known to yield water at a moderate rate.

TOMSTOWN DOLOMITE

The outcrop of the Tomstown dolomite forms a narrow belt at the western foot of the Blue Ridge, west of the basal quartzites. It does not occupy the most thickly populated parts of the area studied, and it is covered with Pleistocene (?) gravel in the central and northern reaches of its outcrop. Consequently it is not widely used as a source of water supplies.

The dolomite looks much like limestone. Its beds are medium in thickness for rock of that type, and the crystalline grain of the rock is moderately coarse. Bedding planes are well marked, as well as joints that transect the beds vertically. The formation has a regional dip to the northwest. Although pure dolomite is less soluble in water than pure limestone, the Tomstown dolomite appears to be nearly as cavernous as most of the limestone in the area, and deep openings have been penetrated by wells. Some of these openings are full of silt or iron oxide, indicating that there is free circulation of water from the surface to deeper zones of the rock.

The five wells in this formation of which records are available are of two different types. Two of these wells are shallow, having been put down for small supplies, and drilling was discontinued when they delivered respectively 10 and 20 gallons a minute. The other three wells are at the du Pont rayon mills at Basic City, near Waynesboro, Augusta County. Here large supplies were needed, and wells of large diameter were put down to depths of 500 to 700 feet. The reported results of pumping tests are respectively 560, 520, and 680 gallons a minute. As these three wells are in one small locality, and as records of wells in the Tomstown dolomite in other localities are scarce, it is impossible to say whether such yields are available in other parts of the outcrop area. Although the wells at Basic City are on the outcrop area and the presence of clay and iron-filled crevices in the rock indicates free circulation of water at considerable depth, artesian pressure was sufficiently developed in the dolomite to cause one of the wells to flow at the ground surface.

Chemical analysis of a single sample indicates that the water in the dolomite at Basic City is low in dissolved solids (64 parts per million), is soft in comparison to limestone waters (total hardness, 62 parts per million), and contains mostly calcium and magnesium carbonate, with a moderately high content of silica.

WAYNESBORO FORMATION

The Waynesboro formation lies adjacent to the Tomstown dolomite and is confined to the vicinity of the foot of the Blue Ridge. Like the Tomstown, the Waynesboro is largely concealed by gravel in the central and northern parts of its outcrop area.

The Waynesboro formation consists chiefly of red or green mudrock and shale interbedded with thin layers of fine-grained sandstone, dolomite, and limestone. Joints appear to be rather few and small on the exposed sections of the formation, but bedding planes and shaly partings are numerous because of the thin-bedded nature of the rock.

In spite of the predominantly fine grain of the material that makes up the Waynesboro formation, the records of four wells that end in the formation indicate that it is a fair source of ground water. These wells range in depth from 90 to 325 feet and yield from 16 to 23 gallons a minute. These yields are exceptionally good for the formations in the area studied, but there can be little doubt that more records of wells would disclose a greater diversity of depth and yield, and it is likely that the average yield of a large number of wells in the Waynesboro formation would be smaller.

The information on water level in the wells in this formation, taken when drilling was completed, indicates that the water in the formation is under some artesian pressure. None of the wells flowed, however.

A chemical analysis of water from a single well in the Waynesboro formation shows that the water has a hardness of 237 parts per million and that, aside from calcium bicarbonate, it is comparatively high in sulphate and iron.

CAMBRIAN AND ORDOVICIAN LIMESTONES, INCLUDING THE ATHENS SHALE

With the Elbrook, Conococheague, Beekmantown, Stones River, and Chambersburg limestones is included the Athens shale, because it occurs with them stratigraphically and geographically and because in many places it is a limestone. These formations occupy the central part of the Valley, between the outcrop of the Waynesboro formation and North Mountain. They are involved in a large synclinorium, which in all counties but Rockbridge is occupied axially by Martinsburg shale and younger rocks that divide the limestone outcrop area into a western and an eastern limb. In Rockbridge County the synclinal structure dies out and the Martinsburg shale is not present. In Shenandoah, Rockingham, Augusta, and Rockbridge counties the limestones crop out

locally and to a moderate extent in the area west of North Mountain.

These rocks consist of limestone, dolomite, shale, and sandstone, both in pure state and mixed together. Some of the limestone is cherty. The rocks are folded diversely, so that their fundamental synclinal arrangement is locally concealed (Pl. 3, B); they are jointed extensively and faulted. The bedding planes, shaly partings, and secondary structural openings are enlarged by the percolating waters. The solution channels and caverns are largest and most numerous near the ground surface, especially in the rolling hills that characterize the Shenandoah Valley, but a few water-bearing openings occur as deep as wells have been drilled in the region, presumably in association with artesian circulation through synclines. (See pp. 39-41.) A description of the formations grouped in this unit is given in the stratigraphic table on pages 16 and 17.

Records of about 300 wells that tap these formations are available. These wells range in depth from 20 to 1,926 feet and in yield from 0 to 140 gallons a minute. The average depth is 170 feet, and the average yield 13 gallons a minute. The relation of the yield of shallow wells to the yield of deep wells is shown in the following table.

TABLE 5.—*Wells ending in Cambrian and Ordovician limestones of the Shenandoah Valley*

Depth (feet)	Number of wells	Range in yield (gallons a minute)	Average yield (gallons a minute)
Less than 100	94	½– 60	12
100–200	136	0–125	14
200–300	51	0– 50	10
300 and more	16	0–140	30

This table indicates no great difference in the average yield of wells less than 300 feet deep. These wells are mostly household or farm wells that were drilled to obtain a moderate or small supply of water. When that supply was obtained, drilling was discontinued. On the other hand, this group includes some wells that were put down without success to 300 feet or less, where the drilling was stopped. The group of wells 300 feet or more in depth have a larger average yield. Some of these wells were put down for the purpose of obtaining a large supply of water, and drilling was continued until the yield was sufficient or the well became very deep. For instance, well 398 is 1,926 feet deep and yields

90 gallons a minute, all of which was obtained above 600 feet. On the other hand, well 563 is about 800 feet deep and yields 140 gallons a minute. Most of this water came in the last 10 feet of drilling. The table indicates that most ordinary wells should not be carried to a greater depth than about 200 feet unless the owner is willing to risk the expense of drilling much deeper. By drilling deeper he may obtain a large supply, but his chances of obtaining a moderate amount of water appear to be no better than if he started a new well. In Rockbridge County the chance that a good supply can be obtained from limestone seems to be less than in other counties. Although the larger supplies are likely to come from wells deeper than 300 feet, a few examples that are exceptions to this rule may be cited. For instance, some shallow wells may yield large supplies of water, as well 19, which is 25 feet deep, yielding 16 gallons a minute; well 395, 160 feet deep, 125 gallons a minute; and well 526, 30 feet deep, 20 gallons a minute. Some deep wells may be failures, as well 51, which is 365 feet deep and yields 1 gallon a minute; well 562, which is 350 feet deep and yields a quart a minute; and well 719, which is 511 feet deep and yields nothing. These examples do not contradict the general interpretation of the table given on page 35, but serve to emphasize the fact that individual results of drilling are unpredictable unless expressed in terms of probability. Most of the 300 wells in the limestone yielded less than 10 gallons a minute at the time of their completion as is shown in the following table:

Table 6.—*Number of wells ending in Cambrian and Ordovician limestones that yield water at given rates*

0-5 gallons a minute	109
6-10 gallons a minute	75
11-20 gallons a minute	80
21-40 gallons a minute	21
41-100 gallons a minute	9
More than 100 gallons a minute	4

More than twice as many wells yield less than 10 gallons a minute as yield 11 to 20 gallons a minute. Relatively few wells yield more than 20 gallons a minute.

In some wells that were reported as failures by the driller, the difficulties were mechanical rather than a lack of water-bearing openings in the rock. In some holes put down in limestone that dips the bit was deflected on a hard layer of rock, then jammed, and the well was ruined. In others, particularly along the foot of

the Blue Ridge and near the National Cemetery, near Staunton, seams full of fluid mud were encountered. If they were at great depth the hole would have to be reamed to a larger diameter so that casing could be driven down. In many such places it was deemed more economical to drill a new well than to enlarge the old one. In a few localities in the area along the Blue Ridge, where thick beds of gravel overlie the limestone, boulders are present in such number that drilling is impossible. Another difficulty encountered rarely is the presence of a large solution channel, or cave, into which the drill may drop, and become caught, thereby ruining the well. If the height of the cavern is greater than the length of the bit, drilling through it is very difficult if not impossible. In a few places wells have been drilled to considerable depth through limestone that contained no fractures and consequently was not water-bearing.

Water in the Cambrian and Ordovician limestone is hard in most places. It contains chiefly calcium bicarbonate, with subsidiary amounts of magnesium and sodium. Iron is present in high and low concentrations, three samples having more than 5 parts per million. Over 30 parts per million of nitrate has been found in several samples. No controlling factor has been discerned to explain the great range in concentration of the mineral matter in the limestone waters.

In the Shenandoah Valley there are several wells 500 feet or more deep drilled into the Cambrian and Ordovician limestones of which detailed information concerning the depth of the water-bearing fissures is available. The data pertaining to the occurrence of water in deep wells in the limestone are set forth in Table 5 and include the altitude above sea level at which water-bearing fissures were reported by the drillers.

An attempt to point out zones in which fissures are especially numerous on a basis of these data appears to be risky. At altitudes of 1,100 to 1,300 feet, 500 to 600 feet, and about at sea level there seem to be some correlative water-bearing zones, but the slight concordance may be purely accidental. Also accidental may be the seeming generalization that the deeper water-bearing zones are more numerous in the northern part of the Valley than in the southern part. However, as it is likely that the data on deep wells here presented are very nearly all that are available in the area at present, the two sets of tentative and questionable correlations will be discussed further.

It appears that limestone may be dissolved at an appreciable rate only when the water is somewhat acid, generally because of

TABLE 7.—*Deep wells in the Cambrian and Ordovician limestones of the Shenandoah Valley, Virginia*

Well No.	Location	Depth (feet)	Yield (gallons a minute)	Depth of water-bearing cavities below surface of ground (feet)	Approximate altitude of well (feet)	Approximate altitude of water-bearing cavities (feet)
W 161 (1931)	Winchester	1,432	150	100, 300, 700, 1,100 to 1,200	700	+600, +400, 0, —400 to —500
W 204 (1931)	2¼ miles west of Stephens City	310	10	310	800	+500
229	Front Royal	519	(1)	460	600	150
397	Harrisonburg	1,322	60	60 and 1,317	1,350	1,300 and 30
398	Harrisonburg	1,926	90	Above 600	1,350	+750 or less
560	Staunton	1,400	40	Below 600	1,400	800 (to sea level)
563	Staunton	801	¼	75 and below 790	1,300	+1,200 and 500 or more
573	Southwest of Staunton	536	6½	325 to 535	1,600	+1,100 to +1,300
719	Lexington	511	0	....	1,000	....

[1] Reported to be very large.

the presence of carbon dioxide. Furthermore, water becomes acid most commonly by coming into contact with decaying vegetable matter in the soil. Therefore it is probable that the acid water which dissolved the limestone at great depths obtained the acidity near the surface and retained it during downward migration. The mechanics of the downward migration of the acid water may be one of the following: (1) Sinking of the water table at some time in the past, with a subsequent rise to its present position; (2) artesian flow along thrust-fault planes that crop out in the vicinity of North Mountain, the water passing downward perhaps gradually percolating upward through devious and initially minute openings and emerging in the lowlands of the valley; (3) artesian flow from the western limb of the synclinorium (whose axis is occupied by the Martinsburg shale and in some places by the younger rocks of the Massanutten Mountain) to the eastern limb, which in the northern counties is at a lower altitude than the western limb.

These possibilities do not provide for juvenile waters from telluric sources, nor for the acidity deep-seated ground waters might acquire from decomposing pyrite, a reaction which requires the presence of air.

(1) Sinking of the water table at some time in the past. Probably there have been times since the beginning of the Pleistocene epoch when the climate was less moist than it is at present, during some of the interglacial stages. If the rainfall had been diminished to a small enough amount the water table might have sunk to very nearly the level of the water gap at Harpers Ferry, W. Va., through which the drainage of the Shenandoah Valley passes by way of the Potomac River. The bottom of this rock-cut gorge through the Blue Ridge was at an altitude of about 400 to 500 feet in the Tertiary period and the early part of the Quaternary period. Thus, if ground-water drainage was continued without interruption through the gap, which is highly probable, the water table could not have been lower than about 500 feet above sea level. If the water table were depressed to 500 feet or less above sea level, the circulation must have been rather more sluggish than it is at present. Even so, with enough time available, the water-bearing cavities from the 500-foot level up to the level of the present water table may have been formed by solution at or near the water table as it fluctuated in response to changes in climate. This process cannot account for the water-bearing cavities deep below the 500-foot level, such as are found in some of the deepest wells. The possibility that there was differential warping of the earth's crust which resulted in the area

near the water gap being depressed to a lower altitude than it is at present is not considered in this discussion.

The scanty data on deep wells seem to suggest that there is a zone at about 500 feet above sea level in which water-bearing cavities are especially numerous. If this suggestion is valid it may indicate that there have been one or more periods when the water table was depressed to the lowest limit of drainage.

(2) Artesian flow along thrust-fault planes. The depth at which thrust faults flatten out toward the horizontal in the Shenandoah Valley is not known. They may be too deep in the vicinity of the wells listed in Table 7 to have any effect on the formation of the water-bearing cavities. Furthermore, the fault planes themselves may be so filled with fault gouge that they do not act as conduits but rather as obstacles to moving ground water. The fault planes are somewhat affected by the folding of the rocks in the area, having been developed apparently after the folding began but not after the folding had ceased. Therefore wells in anticlinal areas might reach the fault planes, whereas wells in synclinal areas might not. However, the well at Winchester and one in Harrisonburg encounter water-bearing openings at about sea level and below, and both cities are situated near the cores of synclines. Hence if the faults are intercepted by the two wells mentioned the fault whose plane crops out along North Mountain must not be very far below the surface in anticlinal areas, and possibly faults are encountered in other areas by shallower wells. The North Mountain fault, west-northwest of Winchester, crops out in a terrane whose altitude is 800 to 1,000 feet above sea level. If shallow-seated ground water passes downward along the fault plane, it probably passes beneath the outcrop of the Martinsburg shale and discharges upward through joints and bedding planes of the limestone in Clarke County and perhaps also in the clastic Lower Cambrian formations near the Blue Ridge. There the altitude of the ground surface is about 500 feet above sea level. Thus the difference in level is 300 to 500 feet in a horizontal distance of 10 to 20 miles, which would give a hydraulic gradient between 15 and 50 feet to the mile. The circulation (if any) must have been very slow at first, but the ascending waters were capable of some solution, and the progress of the water might gradually have become easier. At Harrisonburg the fault trace is at an altitude of 1,500 to 1,800 feet, and the area in which the water would probably have to discharge is within a range of 200 to 700 feet lower. The horizontal distance is at least 8 miles and probably nearer 15 miles, making the effective hydraulic gradient about 25

to 40 feet to the mile. Conditions at Harrisonburg are complicated by the presence of a minor overthrust fault, which crops out about 4 miles east of the city. The records include no wells south of Harrisonburg that are reported to intercept water-bearing fissures below an altitude of 500 feet except one in Staunton, which, however, yields a flow of only a quart a minute.

The explanation of the presence and seeming circulation of fairly fresh and soft water through large openings in the limestone at great depths in terms of artesian migration of the water down thrust-fault planes should probably be looked upon with skepticism in view of the uncertainties mentioned above and also because it is likely that any preexisting structural openings or original openings in the rocks would have been destroyed by the folding and overthrusting that took place in the region. Calcite veins are numerous in the limestone, and it contains some chert, which may have originated during or shortly after the Appalachian deformation. At any rate, it seems likely that in this region, where once a great thickness of younger formations overlay the limestones and where much heat was generated by deformation, the breaks in the rocks were filled with vein material, and that the present water-bearing cavities are of a much more recent date than the thrust faults. Since the mountain making took place there have been great erosion and some minor movements of the earth's crust, which are most probably the cause of the joints and other openings now existing.

(3) Artesian flow from the western limb of a syncline to the eastern limb. It is believed, on the basis of such information as is available, that the water-bearing cavities below the altitude of 500 feet and perhaps many of the cavities above that altitude may best be explained by assuming such a process as the natural artesian flow down one limb of a syncline and up to the surface at a lower altitude on the other limb. In the northern part of the Valley the difference in altitude between the western limb and the eastern limb seems to provide a considerable hydraulic head. Thus at Winchester the difference in altitude between the land surfaces in the west side and the east side of the Martinsburg shale is 200 to 300 feet and the horizontal distance across the outcrop of the shale is about 6 miles; allowing for a hydraulic gradient of 30 to 50 feet to the mile. East of Harrisonburg the synclinal structure is complicated by an overthrust fault which has carried the Massanutten syncline into contact with the smaller syncline on which Harrisonburg is situated in the axial region. The fault probably does not break the continuity of the limestone at depth; the

eastern limb of the smaller syncline crops out immediately east of the city but at an altitude very little lower that that of the western limb. If deep-seated artesian circulation takes place beneath the city it must come from the area to the west, the water emerging near the South River. The hydraulic gradient would be about 30 feet to the mile. South of Harrisonburg the difference in altitude between the western and eastern limbs of the syncline is slight, and it is interesting to note that there is no record of water-bearing cavities below an altitnde of 500 feet. At Front Royal, east of Massanutten Mountain, a cavity that yielded an "unlimited" supply of water was reported at an altitude of 150 feet above sea level. The well that taps this cavity, if the hypothesis of artesian circulation is correct, is in the region of discharge, the water having arrived from the other side of Massanutten Mountain, probably near Toms Brook, Shenandoah County. The destination of the water is probably the lowland north of Front Royal well, for in the region south of the well the eastern limb of the Massanutten syncline has been overridden by the Blue Ridge overthrust mass. The apparent hydraulic gradient is about 15 to 25 feet to the mile.

The numerous slightly thermal springs in the Shenandoah Valley and Allegheny region are apparently the result of artesian circulation through synclinal folds,[4] and it may be that this circulation occurs on a larger scale than is indicated by the springs.

In conclusion, after due apology for the scanty data presented as evidence, it appears that the deep-seated water-bearing cavities encountered by wells in the limestones of the area are best accounted for by an assumed artesian circulation from west to east along the limbs of synclines.

MARTINSBURG SHALE

The Martinsburg shale crops out in three more or less continuous belts in the part of the Shenandoah Valley discussed in this report. The largest outcrop is along the Massanutten syncline, which extends from Frederick and Clarke counties at the northeast to the southwestern part of Augusta County, where the syncline dies out. From a point east of Harrisonburg to the vicinity of Strasburg the Martinsburg shale is overlain by rocks of Silurian and Devonian age, which make up the body of Massanutten Mountain, and the Martinsburg shale crops out along the western and the eastern foot of the mountain. Southwest of Harrisonburg the core of the syncline is occupied by Martinsburg shale.

[4] Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, 1932.

Martinsburg shale is exposed in a line of small and discontinuous synclines that run parallel to North Mountain about 4 miles southeast of the ridge. This belt begins north of Lantz Mills, in Shenandoah County, and continues down to Edom, in Rockingham County. The outcrop begins again at Harrisonburg and continues to Long Glade, in Augusta County. The line of synclines is broken up at this point, and in Rockbridge County an outcrop of Martinsburg shale occurs east of Lexington, but it is not related structurally to the outcrops farther northeast.

The third outcrop area is in part connected with the thrust fault along North Mountain, small outcrops occurring in Shenandoah County. A larger outcrop is present in Rockingham and Augusta counties, where the fault turns sharply eastward. Martinsburg shale crops out in the southwest corner of Rockbridge County where it is involved in a plunging syncline whose core farther northeast is occupied by rocks of Devonian age. This outcrop is not related to North Mountain, for the structure that determines the trend of the mountain dies out in Augusta County.

The Martinsburg shale is a calcareous, evenly laminated dark-colored shale, containing beds of fine-grained sandstone and in its lower part a greater or lesser number of limestone beds. The shale has bedding planes, open joints in many localities, and slaty cleavage where it has been deformed with greater intensity. These openings are capable of some enlargement by solution, but the water-bearing openings, though numerous, are mostly small. Apparently the limestone layers in the shale have hydrologic features, similar to those of pure limestones, such as solution channels. Wells drilled into the Martinsburg shale are characteristically moderate in yield, but reliable, and the water almost always lies near the ground surface as compared with water in nearby limestone wells. Some of the wells in the Martinsburg shale flow at the surface.

In some respects the Martinsburg shale is quite as satisfactory a source of ground-water supplies as the Cambrian and Ordovician limestones discussed above. The average depth of all wells in the Martinsburg shale, in regard to which information was obtained, is about 90 feet, and the average yield 10 to 12 gallons a minute. Compared with the average limestone wells, the average shale well is but little more than half as deep, whereas its yield is only slightly less. The chances of drilling a dry hole are less in the shale than in the limestone. The shale is, therefore, a cheaper source of small, dependable supplies of water. However, the range in yield of shale wells is small, 50 gallons a minute being the high-

est yield reported in a total of 65 wells. There was one dry hole in the 65 wells.

It may be illuminating to summarize in the following way the results of drilling in the Martinsburg shale:

TABLE 8.—*Number of wells ending in the Martinsburg shale that yield water at given rates*

0 to 5 gallons a minute	25
5 to 10 gallons a minute	11
11 to 20 gallons a minute	22
More than 20 gallons a minute	7
	65

The yields of the wells in the above table are based upon bailing or pumping tests carried on by the drillers when the wells were completed.

The 41 wells less than 100 feet deep yield on the average almost as much (11 gallons a minute) as the 24 wells that are more than 100 feet deep (12 gallons a minute). No wells in the shale deeper than 305 feet were reported.

Chemical analyses of six samples of water from wells in the Martinsburg shale show a considerable range in the hardness (153 to 685 parts per million) and in the total amount of dissolved mineral matter. The water with 685 parts per million of hardness has a strong odor of hydrogen sulphide, and iron is precipitated when the water is exposed to the air. Most of the samples were primarily calcium bicarbonate waters but several had more than 200 parts per million of sulphate. Some samples have only negligible quantities of iron but others have as much as 30 parts per million. In general, the water in the Martinsburg shale is rather highly mineralized, is hard, and may be high in sulphate and iron.

An interesting relation exists in the geographic distribution of hardness of the shale waters. The hardest waters are at the north end of the area studied, and the least hard are in the southern part. The hardest samples of the shale water are harder than the hardest samples of limestone waters. Part of the explanation may be that the water-bearing openings in the shale are smaller than those in the limestone and therefore the water moves more slowly and comes into more intimate contact with the rock. Also, the abundance of carbonaceous matter and the presence of pyrite make the water in the shale strongly acid. But why are the waters in the southern part of the shale outcrop softer than those in the

northern part? It is possible that water traveling through limestone on the western limb of the synclinorium, being under pressure, slowly works upward through the shale, adding to its original hardness the lime that is leached from the shale. This artesian circulation is believed to be most vigorous on the northern part of the valley, becoming feebler in the south, where the synclinorium becomes less pronounced and the difference in altitude between the western limb and the eastern limb becomes slighter.

OSWEGO SANDSTONE AND JUNIATA FORMATION

The Oswego sandstone, of small outcrop area, apparently is not important as a source of water supplies. The Juniata formation likewise crops out to a slight areal extent and no records of wells ending in it are available.

TUSCARORA QUARTZITE AND CLINTON FORMATION

The Tuscarora quartzite is the chief "mountain rock" in the Shenandoah Valley, such ridges as Massanutten Mountain and North Mountain being partly, at least, capped by it. The Clinton formation crops out on the flanks of the anticlinal ridges and in the troughlike valley between the twin ridges of Massanutten Mountain. Because these formations crop out in hilly country, mostly uninhabited, they are not widely used as sources of water.

Records of four wells ending in one or the other of these formations indicate that shallow wells may obtain small quantities of water from them. These wells, ranging in depth from 13 to 65 feet, yield respectively, 1, 2, 5, and 10 gallons a minute. One good reason for the shallowness of the wells is the extreme hardness of the Tuscarora quartzite. It took 10 days to drill the 13-foot well. The well that yields 10 gallons a minute ends in Clinton shale. The Tuscarora, besides being very hard, is somewhat brittle, and it is reported that the yield of wells that draw from this formation has been increased by blasting with explosives.

A single analysis of water from the Tuscarora quartzite shows a moderately low concentration of dissolved mineral matter (151 parts per million), moderate hardness (112 parts per million), and comparatively high iron. The dissolved mineral matter is chiefly calcium bicarbonate. The chemical character of the water is probably somewhat influenced by the Clinton formation.

CAYUGA GROUP AND HELDERBERG LIMESTONE

The rocks of the Cayuga group and Helderberg limestone, associated with ridge-making rocks, crop out in hilly and sparsely

populated country. Records of only six wells ending in these limestones are available. In depth they range from 50 to 305 feet, and in yield from 0 to 20 gallons a minute; their average yield is 9 gallons a minute.

A single sample of water from Helderberg limestone shows a hardness of only 117 parts per million, indicating moderately soft water for a limestone.

SANDSTONES AND SHALES OF LOWER, MIDDLE, AND UPPER DEVONIAN AGE

The Oriskany sandstone, Romney shale, Brallier shale, and Chemung and Catskill formations consist predominantly of shale, mudstone, and sandstone. The Oriskany is a uniform-grained thick-bedded sandstone, cemented with calcareous material as well as iron and manganese oxides in many places. Its thickness ranges from almost nothing to 150 feet. The Romney shale is mostly a fissile black shale, but some greenish shale occurs in the lower part, and flaggy sandstone in the upper part. The Brallier shale and Chemung formation consist mostly of stiff, soft green shale or mudstone interspersed with thin regular beds of fine-grained sandstone. The Catskill formation consists largely of red sandstone and shale.

These rocks crop out in the area west of North Mountain. They are folded, but less intensely than many of the rocks in the Shenandoah Valley. Water in this series of formations occurs mostly in bedding planes and joints, as very little if any truly permeable sandstone is present.

Wells in these Middle and Upper Devonian rocks are mostly comparatively shallow and their yields moderate to small. The average depth of 44 wells is 90 feet, and the average yield is 11 gallons a minute. In this respect these wells resemble closely the wells in the Martinsburg shale. The wells range in depth between 26 and 850 feet and in yield between 1 and 50 gallons a minute. No wells were reported to be failures except well 509, 850 feet deep, in which 10 gallons a minute was encountered at 22 feet and cased off by order of the owner. In the next 828 feet only 1 quart a minute was obtained. The next deepest well is 450 feet deep, and it yielded 34 gallons a minute.

The following table shows the numerical distribution of 42 wells whose tested yields are known.

TABLE 9.—*Number of wells ending in rocks of Middle and Upper Devonian age that yield water at given rates*

0 to 5 gallons a minute	10
6 to 10 gallons a minute	17
11 to 20 gallons a minute	11
More than 20 gallons a minute	4

It is doubtful whether the data assembled justify any conclusion as to the advisability of drilling a deep well into these formations in the hope of obtaining a large supply of water—say, 50 gallons a minute. Only one well has been drilled to a depth of more than 500 feet and that was essentially unsuccessful. The information at hand does not afford any optimism for the development of large supplies from deep wells, but the question must be left open for the future.

The water in these rocks is likely to exhibit some artesian head, and flowing wells are not uncommon. One or two flowing wells are so situated that they may be used without pumping, but in most places the flow is so feeble and the head is so low that pumping is necessary. Hence, the artesian pressure is of little economic importance. There is some evidence that in parts of the area the water may be perched, for in one well two water-bearing strata were entered, but when drilling was carried farther the water was lost. It may have drained down the well and passed out into dry beds.

The rocks of Middle and Upper Devonian age, like the other groups discussed, yield waters that vary rather widely in their content of dissolved mineral matter. In seven samples analyzed the hardness ranged from 6 to 100 parts per million and the total dissolved solids from 17 to 213 parts. Iron was found in concentrations from 35 parts per million to .01 part. Much of the water is calcium bicarbonate water, but some is sodium bicarbonate water. An odor of hydrogen sulphide can be detected in much of the water when it has been drawn recently from a well or where it emerges from the rock in springs. The water in these rocks is likely to be corrosive.

PLEISTOCENE (?) AND RECENT SEDIMENTS

There is evidence to indicate that the alluvium of some of the larger mountain streams is capable of yielding large supplies of water if it is properly developed. The alluvium contains coarse sand and gravel, and in many places it is probably of considerable

thickness. Where the alluvium is thick wells could probably be used effectively, but where the alluvium is not thick wells put down to the underlying rock would be limited in yield by the small drawdown that would be possible. Where wells can not operate efficiently it is possible that a ground-water dam, similar to the one constructed at Harrisonburg, might be feasible. (See pp. 88-89.)

A mantle of clay, ocher, silt, sand, gravel, and boulders, of variable thickness and structure occurs most abundantly along the lower slopes and at the foot of the Blue Ridge in Augusta County and between the Blue Ridge and Massanutten Mountain. It occurs to a lesser extent along the western foot of Massanutten Mountain, and it has been reported in wells in various parts of the Shenandoah Valley at considerable distances from the mountain. The wells in which material of this kind was reported are listed by number and their locations are given roughly below.

TABLE 10.—*Location of wells encountering Pleistocene (?) gravel in Shenandoah Valley*

50	2 miles southwest of Woodstock
53	2 miles north of Edinburg
55, 56	"The Narrows," 4 miles northeast of Edinburg
77	1 mile northeast of Mount Jackson
104	1 mile west of New Market
346	3 miles east of Timberville
349	1 mile east of Timberville
387	7 miles north of Harrisonburg
412	2½ miles north of Grottoes
413	1 mile northwest of Grottoes
426	Elkton
616, 617	4 miles southwest of Fishersville
618	7 miles south of Fishersville.

These wells have encountered gravel that has no apparent relation to the present drainage. Other wells drilled in valleys near streams pass into alluvium that may be contemporaneous with this gravel of Pleistocene (?) age, or it may be more recent. The Pleistocene (?) gravel deposits where they are well developed, as along the Blue Ridge, slope downward from the uplands on stream divides like alluvial aprons such as occur in the mountainous and arid parts of the West. Furthermore, back from the mountains they appear to have been deposited on the summits of the erosional remnants of the Valley-floor peneplain; but not in the valleys of streams that here cut into it, indicating that the gravel is less

A. Part of basin of Big Spring near Kerr's Creek Post Office, Rockbridge County. This spring discharges about 4,500 gallons of water a minute.

B. Spring issuing from small cavern in limestone; on road between Brownsburg and Spottswood, in Augusta County.

recent than the dissection of the Valley Floor peneplain. The rock material in the gravel is derived partly from nearby mountain masses and partly from rocks that crop out in the floor of the Shenandoah Valley.

This gravel of Pleistocene (?) age is poorly sorted and composed in the main of material of fine grain, and furthermore it is best developed in areas on the stream divides. Hence in many places it is lacking in ground water, and even where it is saturated it is likely to have low permeability. Information was obtained in regard to 17 wells that derive their supplies from gravel deposits, including a few that end in Recent alluvium. The average depth is 88 feet, and their average yield 10 gallons a minute. The wells range in depth from 15 to 165 feet and in yield from half a gallon to 20 gallons a minute. The gravel, being of slight thickness, does not give promise of being a source of large supplies at any place in the area studied. Many wells not included in the 17 cited above pass through gravel without encountering water and enter bedrock beneath.

The water in the gravel contains objectionable quantities of iron in solution, is muddy, and in spite of continued pumping never clears up. One sample analyzed shows 51 parts per million of hardness and about 5 parts per million of iron.

SPRINGS

The magnitude and abundance of springs in the Shenandoah Valley are intimately related to the kind of rock that crops out at the surface. The structure of the rock, the topographic relief, and other physical factors are also important. Where these other physical factors are about equal, springs are largest and most numerous in areas underlain by limestone and dolomite. The next largest springs are those found in valley alluvium, talus slopes, and other bodies of unconsolidated sediment. The Oriskany sandstone is a well-known geologic formation from which large and numerous springs issue. Other sandstones and shales give rise to smaller and fewer springs.

The following table shows the relative number and magnitude of springs issuing from groups of rocks that have been classified in much the same way as in the discussion of drilled wells. Data on most of the springs are taken from the report on springs of Virginia.[5]

Table 11.—*Number and rate of flow of springs in different rock formations in Shenandoah Valley, Virginia*

Kind of rock	Number	Rate of Flow (gallons a minute)	
		Range	Average
Alluvium	8	80–2,500	601
Pocono sandstone and Tuscarora quartzite	5	1– 20	12
Catskill, Chemung, Brallier, and Romney formations	11	1– 100	24
Oriskany sandstone	8	10– 800	246
Helderberg limestone	10	10–1,000	240
Martinsburg shale	2	2– 200	101
Limestone and dolomite of Lower Cambrian to Middle Ordovician age	95	5–5,300	670

This table indicates that springs flowing 1,000 gallons a minute or more occur almost exclusively in limestone and dolomite. Such springs, if they issue from one opening or system of openings, are the outlets of true underground streams that flow through the cavernous limestone or dolomite. In certain parts of the country underlain by limestone some surface streams flow into sink holes in the limestone and reappear as large springs some distance away. The courses of these underground streams have been traced in some places by exploration, and in other places by introducing colored dyes at the point where the stream disappears and noting the arrival of the dyes at the point where the spring emerges. A few of the large springs in the Shenandoah Valley, such as the Big Spring near Herns Creek, northwest of Lexington, Rockbridge County, are ponds or lakes without any influent surface drainage.

[5] Collins, W. D., Reeves, Frank, Foster, M. D., and Meacham, R. P., Springs of Virginia: Virginia Comm. Cons. and Devel., Div. Water Resources and Power. Bull. 1, 1930.

(See Pl. 4.) They are fed by numerous springs, and the outlets of some of them are creeks of considerable size. Other large springs, like the Ayers Spring, between Murat and Rapps Mill, Rockbridge County, have no such basins, but the underground stream flows directly out of a cavern in the limestone. Large springs are especially abundant in this area between Rapps Mill and Murat and in the vicinity of Waynesboro, Augusta County. The reason for their relative abundance probably lies in the synclinal structure of the rocks which permits the ascent of deeply percolating artesian water or, in the vicinity of Waynesboro, the great topographic relief.

Large springs are somewhat numerous in the valley alluvium in certain localities and in the talus slopes of some of the ridges in the region. In the valley of the Dry River west of Harrisonburg, Rockingham County, springs emerge, and in some places their outflow disappears into the alluvium. The water emerging as springs from such material may be derived from true underflow of a stream, or it may be water, that is emerging from the underlying bedrock. West of Goshen, Rockbridge County, the springs in the alluvium are probably fed, at least in part, by water from the Devonian rocks that crop out there, for the water is rather highly mineralized.

Springs are widely used as sources of water for household, industrial, and municipal supplies in Rockbridge County and to a less extent in the rest of the area covered by this report. Springs are advantageous because the water can be made available at comparatively low cost, for in some localities the water can be piped by gravity to the place where it is to be used. However, where conditions are favorable for drilling wells successfully most of the inhabitants of the Shenandoah Valley have preferred not to depend upon springs, probably because wells are more easily protected from pollution by surface drainage and because most wells are more reliable than springs.

Water from springs is likely to be less highly mineralized than water from wells drilled into the same formation. The reason probably is that most springs are fed by water from the upper part of the zone of saturation. This water is derived from downward-percolating rain and melted snow, and it moves comparatively rapidly through established channelways, whereas in wells the water moves farther vertically, more slowly, and generally through smaller openings. Water from springs in the limestone is only moderately hard, and the so-called "mineral springs" that issue mostly from Devonian rocks in the area west of North Mountain are in reality only moderately high in dissolved mineral content if compared with water from wells in these rocks. The springs fed by water that has traveled down the limb of a syncline and thence upward on the opposite side to its point of issuance are highly mineralized, both because the water has traveled far and because it has become somewhat heated.

Some of the springs in the Shenandoah Valley and area to the west of North Mountain are thermal to the extent that their waters have mean annual temperatures appreciably higher than the mean annual temperature of the air at the point where the spring issues. All springs in the area with mean annual temperatures of 55° F. or more are considered by Reeves[6] to be warm springs. In his survey of the west-central part of the State, Reeves found about 90 such springs. The warmest springs are in Bath and Alleghany counties beyond the western limit of the area discussed in this report. Thermal springs in Virginia are believed to be caused by the percolation of ground water down synclines to depths where the rocks have a higher temperature than they do at the surface. The warm water is propelled by artesian pressure up the opposite limb of the syncline to a point of issuance at a lower altitude than the area of intake.

EBBING AND FLOWING SPRING

The so-called "Tide Spring," on the farm of Cornelius J. Riddle, 5½ miles southwest of Broadway, in Rockingham County, is a feature of unusual interest. It belongs to the class of periodic or ebbing and flowing springs. The following statement has been furnished by O. E. Meinzer, who has made an investigation of this spring and of other ebbing and flowing springs:

"Ebbing and flowing or periodic springs are distinctive features that are entirely different from the ordinary intermittent springs that flow in wet seasons and disappear in dry seasons. An ebbing and flowing spring has periods of flow, when it flows vigorously, and periods of ebb, when it ceases to flow or flows at a greatly reduced rate. The periods of flow may occur at nearly regular intervals or at very irregular intervals; they may occur at intervals of a few minutes or a few hours or even a few days or longer. The springs of this type are nearly all situated far from the sea, and they have no relation whatever to oceanic tides. In their periodic action they resemble geysers, but their water has the normal temperature of ordinary ground water, and they do not generally emit any noticeable amount of gas. All or nearly all ebbing and flowing springs issue from limestone, and as early as 1724 their periodic action was ascribed to natural siphons in the rock.[7]

"The total number of ebbing and flowing springs is very small. After several years of inquiry and search of the literature, the writer has obtained information in regard to only about 20 springs of this kind in the United States and a comparable number in other parts of the world. Doubtless the total number in existence is greater, but the fact remains that they are rare and unusual features.

[6] Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, 1932.

[7] Desaguliers, J. T., Royal Soc. London Philos. Trans., vol. 33, no. 384, p. 132, 1724; abridged ed., vol. 7, pp. 39-41, 1809.

"The so-called 'Tide Spring,' on the farm of Cornelius J. Riddle, near Broadway, Va., is a genuine ebbing and flowing spring, which commonly has periods of flow that alternate with periods in which the water disappears completely. It is situated on a limestone hillside a short distance from the perennial stream into which its water discharges. It consists of a basin which is floored in its central part by a deposit of coarse, clean grit that rests on creviced limestone, through which the water rises during the periods of flow. In a relatively normal period of flow the water rises through the crevices, covers the bottom of the basin, then fills the basin, and starts to overflow. This rise occurs quietly and steadily but decisively, so that approximate maximum discharge may be reached within perhaps a minute from the time the water begins to appear. The basin may then discharge at a rate of several hundred to more than 1,000 gallons a minute for perhaps 10 minutes to half an hour, more or less, when the flow begins to weaken noticeably. Then overflow ceases, and the water goes down and disappears with a few gurgling sounds. The ensuing dormant period is likely to last an hour, but it may be very brief or may last several hours, or even several days, weeks, or months. For several days the spring may be very regular in its periodic behavior, but for any long time it is likely to be so variable and erratic, both in the main features and in the minor details of its performance, that it seems as if its behavior were manipulated by mischievous elves residing in the caverns of the locality who take delight in bewildering and mocking those who endeavor to discover its laws of flow.

"An automatic water-stage recorder was operated on the Tide Spring for a period of about 5 years—from July, 1927, to August, 1932. In order to show the detailed behavior of the spring, the recorder was specially constructed with a time scale of 14.4 inches to the day, or six times the scale commonly used in stream gaging. In Plate 5 is shown, on a greatly reduced scale, the hydrograph obtained by this recorder from July 10, 1927, to February 11, 1928. This hydrograph shows several of the characteristic features of the spring—its great regularity during periods of a day or a few days (for example, December 14 to 16); its puzzling irregularities when considered for the entire time shown, its minor fluctuations of flow superimposed on the main periods of flow, and the tendency for the discharge to be roughly in proportion to the duration of the preceding quiescent period. This last-mentioned feature is perhaps the most puzzling of all. Note, for example, the large discharge in the forenoon and afternoon of February 2, following quiescent periods of a few hours; the larger discharge on January 3, 6, and 20, following quiescent periods between 1 and 2 days long; and the still larger discharge on December 31, following a quiescent period of about 3 days. The most spectacular event, however, recorded in Plate 2, and in the hydrograph for the entire 5 years of record, was the huge discharge in the period of flow, lasting nearly a day, on December 7 and 8, and the

veritable flood that occurred on December 9, at the beginning of a period of flow lasting 3 days. This relatively enormous discharge came after a period of complete quiescence of about 4½ months, from July 18 to December 7. Thus, the phenomenon followed the law of relation of discharge to duration of preceding quiescent period, although it cannot be assumed that the cause was necessarily the same as in the case of the shorter periods of quiescence. If the phenomenon was due merely to an accidental obstruction that impounded the water until it was broken through by the pressure of the water, it must be assumed that the obstruction was not at first fully removed and that a second obstruction developed on December 8 which stopped the discharge for several hours, until the major deluge broke on the morning of December 9.

"The record of the Tide Spring, like the records of other ebbing and flowing springs that have been studied, gives general support to the theory that the periodic performance is due to the action of siphons in cavernous rock. Exacting analysis of the hydrographs that are now available will probably furnish more satisfactory explanation of the many puzzling irregularities than can at present be given. It appears, however, that the principal irregularities are due partly to variations in water supply and partly to variations in the air-tightness of the siphon system, whereas the minor irregularities in many of the periods of flow are probably due to surges produced by variations in the pressure of the entrapped air as the system discharges.

"The variations in water supply are produced chiefly by the alternation of wet and dry seasons and successive freezing and thawing of the ground. In seasons of abundant water an ebbing and flowing spring may lose its periodic character and may flow continuously because the supply exceeds the capacity of the siphon; on the other hand, in dry seasons it may cease to flow because the small supply of water escapes elsewhere, or it may have a continuous flow that is too small to prime the siphon or that comes from other sources. Variations of this type are more obvious in some other ebbing and flowing springs than in the Tide Spring.

"The fact that irregularities in the periodic action may result from variations in the air-tightness of the siphon systems was suggested by the writer and was demonstrated in an experiment by Bridge.[8] The system is likely to be more nearly air-tight when the interstices of the soil and rocks are filled with water than when they are dry or only partly filled, and also probably more nearly air-tight when the ground is frozen than otherwise. The variations in air-tightness may determine whether the system of caverns is discharged completely by the siphon or whether the siphon action is interrupted by air leaks before the discharge is completed. Obviously a great variety of irregularities in discharge may thus result."

[8] Bridge, Josiah, Ebb and flow springs in the Ozarks: Missouri Univ. School of Mines and Metallurgy Bull., vol. 7, pp. 17-26, 1923.

COUNTY REPORTS

SHENANDOAH COUNTY

GENERAL FEATURES

Shenandoah County has an area of 510 square miles. Its population in 1930 was 20,655. Strasburg and Woodstock are the largest communities, with a population respectively of 1,901 and 1,552. The residents are mostly devoted to agriculture, and two-thirds of the area is classified as farm land. Shenandoah County is not a highly industrialized area, for there were only 42 establishments employing a total of 491 workers in 1929. The value of their output during that year was $1,810,135.

The county is drained by the North Fork of the Shenandoah River and its minor tributaries. Most of the county is represented by the rolling floor of the Shenandoah Valley, which is bordered on the east by Massanutten Mountain, and on the west by the chain of ridges generally referred to in this report as North Mountain. There is a narrow valley between the twin ridges of Massanutten Mountain. West of North Mountain the country is mountainous, and the valleys between the ridges are narrow and sparsely settled.

GEOLOGY

The rocks in Shenandoah County range in age from the Elbrook limestone (Middle and Upper Cambrian) to the Catskill formation (Upper Devonian). (See table of rock formations, pp. 14-18.) The oldest rocks crop out between the Valley Turnpike and North Mountain. The structure is mainly anticlinal. The axial region of the anticline is occupied in the northern part of the county by the Elbrook limestone, but the structure there is interrupted by faulting. Farther southwest the Conococheague limestone and Beekmantown dolomite occupy the axis of the anticline. In the southeastern part of the anticline the successive rocks that crop out are younger, for they are influenced by the Massanutten syncline. The Martinsburg shale is extensively exposed along the foot of Massanutten Mountain in a belt about 3 miles wide. The western ridge of Massanutten Mountain is capped by the beveled edge of the eastward-dipping Tuscarora quartzite. On the east slope of the western ridge the Clinton formation, Cayuga group, Helderberg limestone, and Oriskany sandstone crop out in rapid succession. The floor of the valley between the twin ridges of Massanutten Mountain is underlain chiefly by Romney shale.

In the northeast corner of the county the anticlinal belt of limestones that occupy the axis of the Valley has been thrust northwestward

over against Martinsburg shale. The overthrust fault is a major one, known as the "North Mountain fault." Farther southwest in the Valley, however, a subsidiary branch of the main North Mountain fault has thrust these anticlinal limestones against a small syncline, with Martinsburg shale at the axis where it is not completely overridden by the overthrust sheet. This syncline extends from the southwestern border of the county to Fairview, west of Maurertown. Between the syncline and North Mountain the Cambrian and Ordovician limestones are exposed on its western limb. Elbrook limestone is exposed farther west, being adjacent to North Mountain and the chief overthrust fault.

West of North Mountain the Devonian rocks (Romney shale, Brallier shale, Chemung and Catskill formations) underlie by far the most of the area. These rocks are arranged about a syncline whose axis trends northeastward 2 miles east of Orkney Springs. The axis is occupied by the Catskill formation, and the older Devonian and Silurian rocks crop out successively on all sides. Martinsburg shale appears near the North Mountain fault. An anticline parallels this syncline, but its axis is in West Virginia. Another anticline lies to the northeast, in line with the axis of the syncline. Tuscarora quartzite occupies its core, and it forms a ridge.

GROUND-WATER CONDITIONS

Area west of the North Mountain fault.—This area is underlain mostly by rocks of Devonian age, although Silurian rocks and the Martinsburg shale are exposed over smaller areas. All but one of the few wells recorded in this part of the county are drilled into the Devonian sandstone and shale.

The Middle and Upper Devonian formations (Romney, Brallier, Chemung, and Catskill) are fairly similar on a large scale, although there is an increase in the relative amount of sandstone from the older formation to the younger. The beds are deformed into open folds and are not metamorphosed. Joints are characteristic of the sandstone, but the shale seems not to have been so subject to fracturing. Even in most of the shale there are intercalated beds of sandstone, and likewise in the sandy formations certain beds are composed chiefly of shale and mudstone. These rocks may be expected to yield small or moderate supplies of water at fairly shallow depths.

The few wells in this area of which records are available indicate that wells less than 100 feet deep yield moderate supplies. Three wells along Stony Creek north of Orkney Springs seem to be especially successful, being about 75 feet deep and yielding about 16 gallons a minute with only a slight draw-down. At the north end of Little North Mountain in the vicinity of Wheatfield the wells are somewhat weaker. A well

drilled into the Martinsburg shale is the deepest and delivers the weakest supply of all the known wells in the area.

The wells in this part of Shenandoah County are not evenly distributed.

To judge from areas in which the ground-water conditions are known, it may be safe to conclude that along the valley flats and lower terraces wells are probably shallow, yielding small or moderate quantities of water, and the water level is probably within a few feet of the surface. The seasonal fluctuation of the water level is probably small, and consequently the wells are reliable. Some of the wells may flow under artesian pressure, but the flow is likely to be small. On the higher terraces and divides wells of comparable depth probably yield small supplies. However, if the wells here were drilled to the same level as the wells in the lowlands the yield would probably not be very different. The water table in the divide areas is deeper and fluctuates over a greater range from season to season. According to the available data, if the bedrock happens to be Cayuga or Helderberg limestone the wells will yield smaller supplies than wells in the Martinsburg shale and the Devonian shales and sandstones.

It may be inferred that large supplies cannot be obtained easily in the area west of North Mountain, and the data on wells in other counties to the south accord in general with this view. However, a well of large diameter drilled deeper than the usual household well might deliver several times as much water as the shallower and smaller wells. Even so, yields of wells in shale and sandstone in this region do not vary so widely from the average as they do in limestone, and the area west of the North Mountain fault should be regarded primarily as a favorable locality for small or moderate supplies. Dug wells are not recommended except in the valley bottoms, because the soil above the bedrock is thin, and the rock is hard to excavate with hand tools.

The water in the rocks of this area is likely to be soft but moderately high in some dissolved minerals such as iron and silica. Exceptions are waters in the small outcrops of Martinsburg shale and the limestones, which are hard, and the Silurian sandstones, which are likely to be low in all dissolved mineral matter.

Valley region.—The two groups of rocks that constitute the bedrock under most of the Shenandoah Valley are the Cambrian and Ordovician limestones (including the Athens shale) and the Martinsburg shale. The limestones occupy the western part of the Valley, widening toward the south, and the Martinsburg shale crops out in a belt along the foot of Massanutten Mountain.

In the area about Strasburg some of the wells derive their supplies from limestone and some from shale. The wells are mostly of moderate

depth, ranging from about 50 to 300 feet and averaging about 150 feet. Northwest of Strasburg the wells in the limestone yield small amounts, but some of the wells in and near the town deliver large quantities. The best well, owned by the Shenandoah Valley Cooperative Milk Producers' Association, was drilled 155 feet into the shale. It yielded 50 gallons a minute in 1923, when it was drilled, with a draw-down of 29 feet. At that time the static water level was 3 feet below ground. The water is highly mineralized and hard and smells strongly of hydrogen sulphide. The other wells near the town yield from 1 to 16 gallons a minute, the limestone yielding the larger supplies.

The water levels in this vicinity were measured when the wells were drilled and are of only general interest, because they fluctuate considerably with the wetness and dryness of the weather and with the season. The static level is deeper in limestone than in the shale, being as deep as 225 feet in the limestone, and as shallow as 3 feet or even at the surface in the shale. The average depth would probably be 50 to 75 feet, depending on the topographic situation of the well, and other conditions.[9]

In the vicinity of Toms Brook and Maurertown wells of moderate depth yield consistently adequate supplies for ordinary farm or domestic uses. East of the Valley Turnpike, where the shale crops out, the yields are likely to be somewhat smaller than in the limestone belt but not without exception; furthermore, these wells are shallower. Most of the limestone wells are of average depth and yield. Well 28, on the property of W. J. Gochenour, at Maurertown, was drilled by Mr. Gochenour to a depth of 100 feet and yields 35 gallons a minute. This is the best well in the vicinity of which a record is available, for the yield is greatest, and the depth is less than that of most of the wells. Well 27, 300 feet deep, yields only 9 gallons a minute; well 33, 94 feet deep, yields only half a gallon a minute. The average yield, however, is about 12 gallons a minute.

The static level in the wells when they were drilled ranged from 10 to 125 feet below the ground surface. Here as elsewhere, the water level in shale wells is nearer the surface than in limestone, owing to the slower drainage from the shale and perhaps to the local artesian pressure, which may affect the shallow-seated ground water in the shale.

In the area about Woodstock and Edinburg the conditions appear characteristically as favorable as in the area immediately up the Valley. The wells are mostly more than 100 feet in depth, and the average yield is somewhat smaller than that of the wells in the upper area, but the proportion of wells of ample yield to those of questionable adequacy is high. Well 44 is reported to have been tested in 1908 at 34 gallons a minute, and the depth is only 70 feet. On the other hand, wells 50 and

[9] It is important to keep in mind that the water levels as given in this report do not represent the necessary pumping lift, because the draw-down is not taken into consideration.

51, southwest of Woodstock, yield only 1 gallon a minute each, although they are respectively 152 and 365 feet deep. Northwest of Woodstock the surface is covered in many places with a mantle of gravel and sand, which may be locally over 50 feet thick. This material seems to be comparatively unimportant as a water-bearer, and its presence increases the length of casing needed and where it contains boulders makes drilling difficult. Unfortunately its thickness varies from one place to another and cannot be predicted.

Westward from New Market to North Mountain the wells are mostly drilled in limestone, but a few wells in and east of New Market draw from the Martinsburg shale. Generally the limestone wells yield somewhat less than in the more central part of the county, although the difference is not very great. A notable exception is well 87, drilled 136 feet into hard limestone; its yield was tested at 60 gallons a minute. The wells in the shale are mostly from 50 to 100 feet deep and yield 2 to 20 gallons a minute, or an average of 12 gallons a minute. Here again, as in the limestone belt farther to the north, the bedrock is overlain in many places by gravel, which may be 60 feet or more thick, or may be absent altogether. Well 92 derives its entire supply of 10 gallons a minute from the gravel. In most localities, however, the presence of gravel is detrimental to the drilling.

The static level of water in wells is deeper in the southern part of the Valley area than it is farther northeast, probably because the relief is somewhat greater. It ranges from 20 to 160 feet below the surface and averages about 50 feet. The measurements are not contemporaneous but were made at different times in different wells.

This belt of limestone and shale abounds in wells of moderate depth and yield, with few wells that might be considered failures and few that deliver very large supplies. The conditions in this part of the county, as shown by reliable records, are distinctly favorable for small users, and probably large supplies can be developed in many localities. The water is almost everywhere hard, and that in the Martinsburg is high in other dissolved solids such as sodium and sulphate.

Massanutten Mountain area.—Between the twin ridges of Massanutten Mountain north of New Market gap a narrow lowland is developed on rocks that are less resistant than the Tuscarora sandstone. These softer rocks are chiefly of Middle and Lower Devonian age. In this area there are no records of wells of any great depth. Most of the wells, in fact, are less than 100 feet deep, and some less than 50 feet. The yield of these wells is small except for a few that were reported to deliver 16 gallons a minute, with very small draw-down, when they were drilled. The records indicate rather uniform ground-water conditions, comparatively easy drilling, and small to moderate supplies of water

available at shallow depths. Slight artesian head is developed in the Devonian rocks of this area, for the mountain as a whole is synclinal in structure, but there are no records of flowing wells. It is not likely that a very large supply of water could be developed from one well, unless possibly from the Helderberg limestone or Oriskany sandstone, which are buried rather deeply beneath the axial part of the Valley.

In chemical character the water in this area resembles that taken from similar rocks west of the North Mountain fault zone. The water level in the wells, reported at the time of drilling, was in no part of this area deeper than 25 feet, although continued pumping and dry seasons tend to depress the level.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

Edinburg.—Population, 498. Water from three municipally owned springs on Massanutten Mountain about 4 miles south of the town, fitted with concrete basins, is piped to a 500,000-gallon concrete reservoir, about 2 miles south of the town. Thence it flows by gravity into the distribution system. The pressure is about 80 to 120 pounds. The average capacity of the system is estimated at 60,000 gallons a day, but the figure is uncertain because the consumption is not metered. Because no human habitations exist in the intake area of the springs, no sanitation is thought necessary.

Mount Jackson.—Population, 554. The chief supply comes from a stream in Massanutten Mountain, 2 miles east of the town. Water is conducted by gravity to two concrete reservoirs of 450,000- and 1,750,000-gallon capacity. Two wells provide auxiliary supplies; one, a 60-foot well above the reservoir, discharges 8,000 to 10,000 gallons a day into it; the other well is 180 feet deep, yields 18,000 to 20,000 gallons a day, is within the town limits, and discharges directly into the distributing system. The wells are used chiefly in summer. The water is chlorinated at the reservoir in the summer.

New Market.—Population, 464. A small mountain stream in Massanutten Mountain discharges by gravity into an earth-fill 3,200,000-gallon reservoir impounded by a concrete dam. The reservoir is about 2 miles southeast of the town. A well half a mile southeast of the town is connected to the conduit from the reservoir to the town. It is 450 feet deep and yields about 35 gallons a minute. It has never been necessary to pump the well.

Strasburg.—Population, 1,901. A small mountain stream on the east slope of Massanutten Mountain is impounded by a dam into a 20,000,000-gallon reservoir. The water passes through a tunnel 1,664 feet long in the mountain. About six springs on the west slope of the moun-

tain about 1 mile south of the town discharge into a 1,000,000-gallon concrete reservoir on the mountain. None of the springs are open, and some have concrete basins. Water passes by gravity from the reservoirs into the distributing system. The pressure ranges from 160 to 180 pounds in the town. The original water supply was derived from the springs. The dam on the east side of the mountain was built in 1923. It has always leaked, for it was not anchored in bedrock. It was satisfactory, however, until 1930, when a water shortage threatened. Some of the springs were improved, and temporary pipe lines were laid out to an abandoned limestone quarry and to Borum Spring, near the town. Since that time the system as described above has been sufficient except for a period in the summer of 1931, when water was brought in from Borum Spring. The water is chlorinated at the reservoir on the west side of the mountain.

Woodstock.—Population, 1,552. Two separate gravity systems are partly or wholly derived from springs. The Little Stony Creek system, with an intake 12 miles west of the town, is supplied by a stream with an impounding dam. Springs feed into the earth-fill reservoir, which has a capacity of 3,000,000 gallons. The water is piped by gravity. The second system is supplied by springs on the west side of Massanutten Mountain, 3 miles southeast of the town. Each spring is walled with concrete. They discharge into two earth-fill reservoirs having a combined capacity of 2,000,000 gallons. From the reservoirs the water is piped to the town by gravity. The pressure is about 265 pounds and has to be diminished before the water is used. The water is chlorinated at a plant on the pipe line.

TABLE 12—*Records of wells*

(All wells

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
1	6¼ miles northwest of Strasburg..	Thomas C. Himelwright	W. J. Gochenour..	1914	....	79
2	5½ miles north-northwest of Strasburg.	Will Everett..........	Charles Fisher....	....	Near edge of stream terrace.	122
3	4½ miles north of Strasburg......	W. A. Pangle..........	W. J. Gochenour..	1925	....	167
4	4 miles north of Strasburg........	F. N. Heihman........	W. J. Gochenour..	1923	....	156
5	3¼ miles north of Strasburg......	Miss M. B. Pingley....	W. J. Gochenour..	1922	....	56
6	3¼ miles northeast of Strasburg...	Jas. R. Burner........	W. J. Gochenour..	1919	....	206
7	1 mile northeast of Strasburg.....	Miss Eleanor Davidson.	W. J. Gochenour..	1921	....	59
8	¾ mile north of Strasburg........	F. S. Strossnider......	W. J. Gochenour..	1918	....	254
9	¾ mile north of Strasburg........	G. H. Bowman........	W. J. Gochenour..	....	....	154
10	Strasburg......................	Bob Sonner...........	Turner Catlett....	....	....	297
11	Strasburg......................	Shenandoah Valley Cooperative Milk Products Association.	W. J. Gochenour..	1923	....	155
13	2 miles west of Strasburg.........	Strasburg Orchard Co..	W. J. Gochenour..	1921	Hilltop...	113
14	1½ miles west-southwest of Strasburg.	S. M. Childs..........	W. J. Gochenour..	....	....	150
15	2 miles south of Strasburg........	W. D. Millne.........	W. J. Gochenour..	1917	....	150
16	2¾ miles southwest of Strasburg..	Mr. Riley............	Totten...........	....	....	84
17	4 miles west-southwest of Strasburg.	Edgar Bly............	W. J. Gochenour..	1917	....	118
18	2¾ miles west of Toms Brook....	E. S. Maphis.........	W. J. Gochenour..	1919	....	115
19	2¼ miles west of Toms Brook.....	Mrs. D. M. Coby.....	W. J. Gochenour..	1908	....	25
20	¾ mile west of Toms Brook......	Josiah Kibler.........	W. J. Gochenour..	1925	....	118
21	½ mile north of Toms Brook.....	Frank Artz...........	W. J. Gochenour..	1911	....	109
22	Toms Brook....................	B. B. Deviers.........	W. J. Gochenour..	1911	....	35
23	1 mile east of Toms Brook........	Jas. Bauserman.......	W. J. Gochenour..	1916	....	59
24	½ mile south of Toms Brook.....	Rockdale Lime Co.....	W. J. Gochenour..	1907	....	45
25	1½ miles southeast of Toms Brook	M. E. Rhodes.........	W. J. Gochenour..	1908	....	44
26	¾ mile east of Maurertown.......	W. E. Shaver.........	Fred Stickley.....	....	....	66
27	Maurertown....................	Shenandoah hatchery..	W. J. Gochenour.. (first 90 feet Mr. Totten).	....	....	300
28	Maurertown....................	W. J. Gochenour......	W. J. Gochenour..	1932	Hillside..	100
29	Maurertown....................	W. J. Gochenour......	W. J. Gochenour..	....	Hillside...	108
30	Maurertown....................	Board of Supervisors of Shenandoah County.	W. J. Gochenour..	1931	....	132
31	¾ mile southwest Maurertown....	G. B. Saum...........	W. J. Gochenour..	1921	....	116
32	2 miles south of Maurertown......	Peter Artz............	W. J. Gochenour..	1908	....	78
33	1¾ miles northeast of Woodstock..	S. K. Hottel..........	W. J. Gochenour..	1909	....	94

[1]May, 1932. [2]September, 1932.

in Shenandoah County, Virginia

drilled)

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale......	Chemung.........	20	7	....	....	1
Shale......	Brallier..........	....	....	....	Analysis on page 70.	2
Shale......	Martinsburg......	36	1	....	....	3
Limestone..	Conococheague....	80	4	....	....	4
Limestone..	Conococheague....	....	3	....	Analysis on page 70.	5
Limestone..	Beekmantown.....	46	16	Very small.	....	6
Limestone..	Chambersburg....	....	2	....	....	7
Limestone..	Stones River......	90	7	....	Rock was "seamless" to the bottom of the well.	8
Shale......	Martinsburg......	....	1	....	....	9
Limestone..	Chambersburg....	225	16	Very small.	....	10
Shale......	Martinsburg......	3	50	29	Affected nearby wells when pumped. Analysis on page 70. H_2S odor and iron sediment.	11
Limestone	Beekmantown.....	50	16	Very small.	At 111 feet a 12-foot water-filled cavern was encountered.	13
Shale and limestone.	Athens (?)........	12	5½	....	3 water horizons in this well.	14
Shale......	Martinsburg......	32	16	Very small.	Water at 60 and 145 feet. Sulphurous water at 141 feet.	15
Limestone..	Stones River......	....	20	Very small.	Mud-filled fractures in the limestone encountered above 47 feet. Sulphurous water at 145 feet. Draw-down test 2 hours.	16
Limestone..	Conococheague....	32	16	Very small.	Water-bearing crevice encountered at 109 feet.	17
Limestone..	Elbrook..........	75	16	Very small.	....	18
Limestone..	Conococheague....	14	16	Very small.	Water-bearing crevice 1 foot high. Analysis on page 70.	19
Limestone..	Conococheague....	35	6	....	Streams at 70 and 105 feet.	20
Shale and limestone.	Athens (?)........	39	9	....	....	21
Limestone..	Beekmantown.....	15	16	Very small.	....	22
Shale......	Martinsburg......	35	2	....	....	23
Limestone..	Chambersburg....	....	5	....	....	24
Shale......	Martinsburg......	10	9	....	....	25
Limestone..	Chambersburg....	....	3½	....	The 90-foot well drilled by W. J. Gochenour had practically failed.	26
Blue limestone.	Beekmantown.....	....	9	....	....	27
Limestone..	Beekmantown.....	[1] 35 [2] 45	35	....	3-inch water-filled opening in rock at 80 feet. Fairbanks-Morse Electric pump.	28
Limestone..	Beekmantown.....	70	25	....	Analysis on page 70.	29
Shale......	Athens...........	30	10	....	3 streams. Water from lowest horizon sulphurous.	30
Limestone..	Beekmantown.....	50	16	Very small.	....	31
Shale......	Martinsburg......	43	3	....	....	32
Limestone..	Beekmantown.....	40	½	....	....	33

TABLE 12—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
34	2¾ miles east of Woodstock	G. I. Wright	W. J. Gochenour	1908	....	43
35	2 miles east of Woodstock	Marcellus Boyer	W. J. Gochenour	1908	....	108
36	3½ miles north of Woodstock	W. L. Saum	W. J. Gochenour	1906	....	82
37	3¼ miles north-northwest of Woodstock.	Isiah Rau	W. J. Gochenour	1906	....	104
38	2¼ miles north-northwest of Woodstock.	G. L. Haun	W. J. Gochenour	1908	....	39
39	1¼ miles north of Woodstock	J. L. Boyer & Co	W. J. Gochenour	1917	....	204
40	1½ miles northwest of Woodstock.	Mrs. Barbara E. Gochenour.	W. J. Gochenour	1907	....	87
41	¾ mile northwest of Woodstock	Tavenner & Graveley	W. J. Gochenour	1914	....	181
42	5¼ miles northwest of Woodstock.	W. D. Walker	W. J. Gochenour	1909	....	220
43	5 miles northwest of Woodstock	Lorenzo Clark	W. J. Gochenour	1908	....	83
44	4¾ miles northwest of Woodstock.	S. J. Reedy	W. J. Gochenour	1908	....	70
45	4½ miles northwest of Woodstock.	Shenandoah County School Board.	W. J. Gochenour	1924	....	63
46	4½ miles northwest of Woodstock.	H. C. Stauffer	W. J. Gochenour	1922	....	120
47	6¾ miles west-northwest of Woodstock.	J. L. McDaniels	W. J. Gochenour	1910	....	40
48	3 miles northwest of Woodstock	W. J. Wilkins	W. J. Gochenour	1908	....	45
49	2¼ miles west-southwest of Woodstock.	M. F. Einswiler	W. J. Gochenour	1916	Floor of alluvium-filled valley.	211
50	2¼ miles west-southwest of Woodstock.	W. H. Sheetz	W. J. Gochenour	1911	....	152
51	1¼ miles southwest of Woodstock.	J. E. Faltz	W. J. Gochenour	1924	....	365
52	2¼ miles southwest of Woodstock.	Charles Sheetz	W. J. Gochenour	1907	....	145
53	2½ miles north of Edinburg	Charles G. Coffman	W. J. Gochenour	1911	....	115
54	3½ miles northeast of Edinburg	Dr. Ford	Grant & Wade Turner.	1930	....	164
55	3¾ miles northeast of Edinburg	Golladay & Newman	W. J. Gochenour	1908	....	122
56	3¾ miles northeast of Edinburg	Virginia Board of Prisons.	Grant & Wade Turner.	....	....	254
57	4¾ miles northeast of Orkney Springs.	George Funkhouser	Grant & Wade Turner.	1929	....	71
58	3¼ miles northeast of Orkney Springs.	George Spitler	Grant & Wade Turner.	1931	....	78
59	2 miles northeast of Orkney Springs.	Clarence Funkhouser	Grant & Wade Turner.	1929	....	74
60	6 miles west of Edinburg	S. G. Funkhouser	W. J. Gochenour	1910	....	112
61	2¼ miles west of Edinburg	R. J. Lantz	W. J. Gochenour	1914	....	180
62	Edinburg	W. H. Stoneburner	W. J. Gochenour	1908	....	44
63	Bowman	A. L. Lindamood	W. J. Gochenour	1914	....	200

Shenandoah County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale......	Martinsburg......	7	16	Very small.	....	34
Shale......	Martinsburg......	38	2	....	Analysis on page 70.	35
Limestone..	Conococheague....	5	1	....	....	36
Limestone..	Beekmantown.....	20	1	....	....	37
Limestone..	Conococheague....	19	15	....	....	38
Limestone..	Conococheague....	50	13	....	....	39
Limestone..	Conococheague....	20	2	....	Streams at 35 and 62 feet.	40
Limestone..	Beekmantown.....	....	10	....	Ocherous material from 126 to 130 feet. Well failed, recovered, then failed again in 1932. Limy sediment in water.	41
Limestone..	Conococheague....	81	2	....	....	42
Limestone..	Conococheague....	23	½	....	....	43
Limestone..	Beekmantown.....	25	34	....	Well previously attempted, passed into a mud-filled crevice at 45 feet and was abandoned.	44
Limestone..	Beekmantown.....	10	20	10	"Dirt" to 35 feet; sand and gravel 6 feet; boulders, 12 feet.	45
Limestone..	Beekmantown.....	70	17	Very small.	Streams encountered at 85, 95, and 115 feet.	46
Limestone..	Elbrook..........	....	4	....	....	47
Limestone..	Beekmantown.....	27	20	....	....	48
Limestone..	Conococheague....	16	3	....	Just north on hill a well struck boulders and was abandoned.	49
Limestone..	Conococheague....	....	1	....	Boulders and soil to 26 feet, limestone to 58 feet, 14 feet of sandstone, then limestone.	50
Limestone..	Beekmantown.....	6	1	....	....	51
Limestone..	Beekmantown.....	125	3	....	....	52
Gravel.....	Pleistocene (?)....	95	5	....	Many boulders throughout well; no bedrock	53
Shale......	Athens...........	....	15	....	....	54
Limestone..	Beekmantown.....	38	24	....	15 feet of soil, 106 feet of limestone with streams at 47 feet and a 6-inch one at 115 feet.	55
Limestone..	Stones River......	....	3	....	19 feet of soil above the limestone. Well cased to 24 feet.	56
Shale......	Chemung.........	12	16	Small..	Well cased to 10 feet.	57
Shale......	Chemung.........	....	16	Small..	20 feet of soil above the shale. Well cased to 31 feet.	58
Shale......	Chemung.........	10	17	Small..	8 feet of soil above the shale. Analysis on page 70. Well cased to 16 feet.	59
Limestone..	Conococheague....	52	16	Small..	Water-bearing crevice at 102-foot level. Analysis on page 70.	60
Black and gray limestone.	Stones River......	80	3	....	....	61
Limestone..	Beekmantown.....	22	10	....	9 feet of soil.	62
Limestone..	Conococheague....	145	16	6	Seam of fluid mud encountered in a cavity 1 foot wide at bottom and mud came 40 feet up into the well. Draw-down test 3 hours.	63

TABLE 12.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
64	Bowman	W. D. Painter	W. J. Gochenour	1911		75
65	Bowman	Mrs. E. B. Shelley	W. J. Gochenour	1911	Hillside	30
66	3¾ miles northeast of Dietrich	F. Rittenour	W. J. Gochenour			57
67	2½ miles northeast of Dietrich	D. G. Funk	W. J. Gochenour			40
68	2½ miles northeast of Dietrich	Samuel Cullers	W. J. Gochenour			28
69	½ mile northeast of Dietrich	J. W. Munch	W. J. Gochenour			38
70	½ mile northeast of Dietrich	A. G. Lichliter	W. J. Gochenour			38
71	½ mile northeast of Dietrich	William Planger	W. J. Gochenour			64
72	2 miles southwest of Dietrich	J. A. G. Clem	W. J. Gochenour	1907		82
73	2¾ miles southwest of Dietrich	St. David's Church	W. J. Gochenour	1907		47
74	4¼ miles southwest of Dietrich	M. J. Habron	W. J. Gochenour			123
75	4¾ miles southeast of Edinburg	P. M. Crisman	W. J. Gochenour	1907		45
76	2 miles south-southeast of Edinburg.	J. D. Lemmon	W. J. Gochenour	1914		176
77	1¼ miles northeast of Mount Jackson.	C. C. Bowman	Grant & Wade Turner.	1929		111
78	1¼ miles north of Mount Jackson.	J. M. Kagey	Grant & Wade Turner.	1906		80
79	¼ mile north of Mount Jackson	Standard Oil Co. of New Jersey.	Grant & Wade Turner.	1917		179
80	Mount Jackson	J. D. Galladay	Grant & Wade Turner	1906		140
81	4¾ miles northwest of Mount Jackson.	J. W. Lonas	Grant & Wade Turner.			15
82	3 miles northwest of Mount Jackson.	G. W. Minnick	Grant & Wade Turner.	1910		52
83	5¼ miles west of Mount Jackson	J. L. Sager	Grant & Wade Turner.	1910		187
84	3¼ miles west of Mount Jackson	John Harpine	Grant & Wade Turner.	1906		48
85	2¼ miles west of Mount Jackson	Abram Harpine	Grant & Wade Turner.	1906		187
86	3 miles west-southwest of Mount Jackson.	Lemuel Fitzmoyer	Grant & Wade Turner.	1906		221
87	5¾ miles northwest of New Market.	J. Carson Miller	Grant & Wade Turner.	1905		136
88	4¾ miles northwest of New Market.	Noah Garber	J. T. Helbert			210
89	4 miles west-northwest of New Market.	John Zirkle	J. T. Helbert			160
90	3¼ miles north of New Market	Shenandoah Caverns	W. J. Gochenour	1923		257
91	1¾ miles northwest of New Market.	M. A. Price	W. J. Gochenour	1909		129
92	2½ miles west-northwest of New Market.	Charles Estep	J. T. Helbert		Bottom lands.	60
93	2½ miles west-northwest of New Market.	Professor Stirewalt	J. T. Helbert			60
94	6½ miles northeast of New Market.	Rose Showns	W. J. Gochenour			76
95	6½ miles northeast of New Market.	Elmer Showns	W. J. Gochenour			94
96	5¼ miles northeast of New Market.	Lee Long	W. J. Gochenour	1918		148

Shenandoah County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone..	Conococheague....	40	16	Small..	7½ feet of soil.	64
Limestone..	Conococheague....	7	9	....	....	65
Shale......	Romney..........	....	1	....	....	66
Shale......	Romney..........	....	6½	....	....	67
Black shale.	Romney..........	....	13	....	Water contains hydrogen sulphide.	68
Shale......	Romney..........	....	5	....	....	69
Shale......	Romney..........	....	6	....	....	70
Shale......	Romney..........	....	6	....	....	71
Shale......	Romney..........	25	16	Small..	4 water-bearing crevices encountered.	72
Shale......	Romney..........	4	3	....	Streams at 14 and 18 feet. Analysis on page 70. Water used for drinking.	73
Shale......	Romney..........	....	5	....	....	74
Shale......	Romney..........	10	16	Small..	....	75
Shale and limestone.	Athens...........	100	10	4	38½ feet sand and gravel; 31½ feet shale; then limestone.	76
Limestone..	Beekmantown.....	....	20	....	63½ feet soil and loose rock, rest limestone. Cased to 102 feet.	77
Limestone..	Beekmantown.....	30	3	....	....	78
Limestone and sandstone.	Conococheague....	73	16	Small.	Three previous attempts at drilling failed. 170 feet of limestone, sandstone, then ocher at bottom. Analysis on page 70.	79
Limestone..	Conococheague....	16	3	....	Vertical limestone dry when drilling ceased; water brought with charge of dynamite.	80
Gravel.....	Pleistocene (?)....	....	½	....	....	81
Limestone..	Athens...........	20	9	....	Nearby 3 holes were put down unsuccessfully. Water bearing fissures at 37 and 46 feet.	82
Limestone (or dolomite).	Beekmantown.....	77	1	....	Limestone was very hard. Seam at 77 feet.	83
Shale......	Martinsburg......	8	16	Small..	....	84
Gray limestone.	Chambersburg....	....	1	....	....	85
Gray limestone.	Stones River......	160	1	....	Several unsuccessful attempts to drill were made nearby.	86
Limestone..	Athens...........	90	60	....	Limestone was very hard.	87
Limestone..	Beekmantown.....	....	20	....	....	88
Limestone..	Beekmantown.....	....	8	....	....	89
Limestone..	Conococheague....	148	7	....	2 unsuccessful wells drilled nearby. 84 feet limestone; 18 feet of mud which was cased off. Water at 178, 208 and 248 feet.	90
Limestone..	Beekmantown.....	....	16	Small..	31 feet of soil above the limestone.	91
Boulders of limestone and mud.	Pleistocene (?)....	....	10	....	....	92
Boulders of limestone and mud.	Pleistocene (?)....	....	20	....	....	93
Shale......	Martinsburg......	47	13	....	....	94
Shale......	Martinsburg......	....	5	....	....	95
Limestone..	Stones River......	70	16	Small..	....	96

TABLE 12—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
97	3½ miles northeast of New Market.	Virginia State Prison Board.	Grant & Wade Turner.	....	....	103
98	3½ miles northeast of New Market.	Harry Martz..........	Grant & Wade Turner.	1931	....	75
99	2¾ miles northeast of New Market.	William Wright.......	W. J. Gochenour..	1908	....	62
100	2¼ miles northeast of New Market.	Forrest Hoffman......	Grant & Wade Turner.	1930	....	67
101	2¼ miles northeast of New Market.	Mrs. S. V. McCormick.	Grant & Wade Turner.	....	....	120
102	½ mile northeast of New Market..	Mrs. Mattie Good.....	Grant & Wade Turner.	1906	....	86
103	New Market....................	R. L. O'Rourk........	Grant & Wade Turner.	1906	....	78
104	1 mile west of New Market.......	Virginia Conference Agency.	Grant & Wade Turner.	1908	....	99
105	New Market....................	R. L. Shirley..........	Grant & Wade Turner.	1929	....	90
106	New Market....................	Frank Strickler........	Grant & Wade Turner.	....	....	57
107	2½ miles east of New Market.....	B. H. Sowers.........	Grant & Wade Turner.	....	....	99
108	3 miles east of New Market.......	D. L. Kuffman........	Grant & Wade Turner.	1931	....	130

Shenandoah County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale......	Athens...........	....	6	....	Diameter 6 inches.	97
Shale......	Martinsburg......	....	10	....	Well cased to 20 feet.	98
Shale......	Martinsburg......	20	2	....	....	99
Shale......	Athens...........	....	4	....	....	100
Blue limestone.	Chambersburg....	49	7	....	....	101
Shale......	Martinsburg......	....	20	....	....	102
Limestone..	Chambersburg....	20	3	....	Analysis on page 70.	103
Limestone..	Athens...........	45	23	2	6½ feet dirt, 17½ feet gravel, 21 feet dirt then "broken" limestone.	104
Shale......	Martinsburg......	....	16	Small..	....	105
Shale......	Martinsburg......	....	4	....	Well cased to 10 feet.	106
Shale......	Martinsburg......	....	5	....	Well cased to 42 feet.	107
Shale......	Martinsburg......	....	16	Small..	Well cased to 4 feet.	108

TABLE 13.—*Analyses of ground waters from Shenandoah County, Virginia*

(Analyst, E. W. Lohr. Parts per million. Numbers at heads of columns refer to corresponding well numbers in preceding table.)

	2	5	11	19	29	35	59	60	73	79	103
Silica (SiO_2)	....	....	....	....	....	21	....	8.4	....	....	....
Iron (Fe)	[1] 34	[1] 5.3	0.99	1.5	....	.09	....	.13	[1] 28	2.3	....
Calcium (Ca)	[2] 10	138	228	79	94	145	[2] 26	61	[2] 16	116	166
Magnesium (Mg)	....	49	28	34	18	17	....	26	....	21	10
Sodium (Na)	[3] 6.3	[3] 30	[3] 30	[3] 1.1	[3] 2.4	16	[3] 8.3	.9	[3] 2.6	[3] 10	[3] 60
Potassium (K)						1.0		1.3			
Bicarbonate (HCO_3)	92	207	418	332	310	286	118	292	86	414	332
Sulphate (SO_4)	[2] 12	[2] 22	332	27	[2] 18	213	[2] 12	5.4	[2] 5	[2] 24	[2] 50
Chloride (Cl)	4.0	32	44	6.0	12	6.2	2.0	1.9	2.0	9.0	94
Nitrate (NO_3)	.20	464	.20	38	30	.10	.10	9.0	2.6	26	159
Total dissolved solids (calculated)	....	837	868	349	327	[4] 589	119	[4] 263	....	410	703
Total hardness as $CaCO_3$ (calculated)	[4] 80	546	685	337	309	432	[4] 94	259	[4] 75	376	456
Date of collection (1933)	May 11	May 11	May 11	May 11	May 11	May 11	May 11	May 11	May 12	May 11	May 10

[1] Turbid with precipitated iron when collected.
[2] By turbidity.
[3] Calculated.
[4] Determined.

WARREN COUNTY

GENERAL FEATURES

Warren County has an area of 216 square miles. Its population in 1930 was 8,340. Front Royal is the largest community in the county, having a population of 2,424. The residents are mostly devoted to agriculture, and about half of the area is classified as farm land. The county is not highly industrialized, for there were only 17 industrial establishments, employing 462 workers in 1929. The value of their output during that year was $3,091,986.

Warren County lies in the valley between the Blue Ridge on the east and Massanutten Mountain on the west. It is drained by the South Fork of the Shenandoah River and its minor tributaries from the mountains. The relief is somewhat greater in this part of the Shenandoah Valley than it is west of Massanutten Mountain. The river occupies a deeply trenched course, and most of the country is characterized by rather pronounced hills except at the north end.

GEOLOGY

The west half of Warren County is underlain by Martinsburg shale, which dips under Massanutten Mountain. The east half of the county south of Front Royal is underlain by pre-Cambrian crystalline rocks, which constitute a projection of the Blue Ridge overthrust mass beyond the line that the fault follows in most of its extent. North of Riverton the basal quartzites of the Cambrian overlie the pre-Cambrian rocks normally and crop out along the lower slopes of the Blue Ridge. The Tomstown dolomite, Waynesboro formation, Elbrook and Conococheague limestones, and Beekmantown dolomite occupy most of this area east of the outcrop of the Martinsburg shale. The Pleistocene (?) gravel that is so abundant along the Blue Ridge farther southwest is scarce in Warren County.

GROUND-WATER CONDITIONS

Warren County presents less variety of ground-water conditions than Shenandoah County because the rocks that occur there are more homogeneous. The Martinsburg shale crops out in a broad belt adjacent to Massanutten Mountain on the west; limestone occupies most of the east half of the county except in the extreme east and southeast where

the pre-Cambrian rocks of the Blue Ridge province occur; and gravel covers the bedrock in many places in the southwestern part of the county.

The wells in the central and western parts of the county are mostly from 50 to 150 feet deep and average about 100 feet. The yield ranges mostly from 10 to 20 gallons a minute. Well 229 is 519 feet deep, and the yield is described by the driller as "unlimited," an 8-foot cavity in the limestone having been encountered at 460 feet which provided a supply of water that could not be lowered perceptibly by bailing. This well is about 1¼ miles south of Front Royal. A 27-foot well drilled into the Martinsburg shale near Waterlick showed a yield of 30 gallons a minute with a very slight draw-down. At the other extreme there are a few wells which are practically failures. Their depth is small except for well 202 (182 feet) and well 223 (327 feet). An exceptionally favorable locality for drilling, according to the records available, seems to be the southwestern part of the shale belt between the Shenandoah River and Massanutten Mountain. No section contains any great number of weak wells, although in the vicinity of Cedarville the wells yield less than the average for the rest of the wells in the county.

In the extreme eastern and southeastern parts of the county a few well records indicate that the pre-Cambrian rocks are a fairly good source of ground water. This is rather surprising in view of the fact that in the northern part of the Piedmont province similar rocks are very poor waterbearers. It is possible that if more records were at hand the outlook would not be so favorable. As it is, however, wells of small depth are reported to yield moderate quantities of water—on the average about 15 gallons a minute.

The gravel that overlies the bedrock in the southwestern part of the county has been somewhat dissected by erosion. For that reason, perhaps, no wells obtain any considerable amount of water from it, for the drainage of ground water may be too rapid to allow for permanent storage. Indeed, the drillers mention the difficulty in drilling occasioned in some places by the presence of boulders, which deflect and jam the bit. None of the records give any clue to the thickness of the gravel in the county, but in some places it is probably 50 feet or more.

Only one well was reported to flow at the surface (well 215), and the head was too small to be of any economic importance. Elsewhere the water level is mostly from 40 to 60 feet below the surface, but probably somewhat shallower in the Martinsburg shale outcrop area.

Chemical analyses of the ground waters indicate that the limestone water is hard, but generally suitable for most uses. Water in the shale

is likely to be very highly mineralized and not satisfactory for certain uses.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

No public water supplies in Warren County are dependent on ground water.

TABLE 14—*Records of wells*

(All drilled

No.	Location	Owner or name	Driller	Depth (feet)
200	3 miles north-northeast of Cedarville	F. K. Weaver	John Rinker	92
201	2¾ miles northeast of Cedarville	—— Weaver	John Rinker	101
202	1¾ miles northeast of Cedarville	George Lee	John Rinker	182
203	2 miles east-northeast of Cedarville	Thompson Sowers	John Rinker	220
204	½ mile west of Cedarville	H. E. Nailor	John Rinker	42
205	Cedarville	C. H. Donovan	J. M. Totten & Son	78
206	3 miles west-northwest of Cedarville	J. C. Beatty	John Rinker	104
207	3 miles west of Cedarville	John Rinker	John Rinker	74
208	1½ miles east-northeast of Waterlick	W. A. Buck	J. M. Totten & Son	127
209	Waterlick	D. F. Frederick	J. M. Totten & Son	75
210	Waterlick	Thomas Derflinger	J. M. Totten & Son	105 55
211	½ mile southeast of Waterlick	R. A. Mitchell	J. M. Totten & Son	40
212	1¼ miles east-southeast of Waterlick	J. T. Colman	J. M. Totten & Son	27
213	2 miles east-southeast of Waterlick	Grandison Catlett	J. M. Totten & Son	57
214	2 miles southeast of Waterlick	A. Huffman	J. M. Totten & Son	125
215	2¼ miles east-southeast of Waterlick	Dr. King	J. M. Totten & Son	78
216	2¾ miles east-southeast of Waterlick	Warren County School Board	J. M. Totten & Son	87
217	2¼ miles west-northwest of Riverton	J. M. Totten	J. M. Totten & Son	87
218	1½ miles west-northwest of Riverton	J. M. Totten	J. M. Totten & Son	67 105
219	½ mile west of Riverton	Morgan Duck Farm	J. M. Totten & Son	125
220	1¼ miles north of Front Royal	James Marshall	J. M. Totten & Son	147
221	¾ mile north of Front Royal	Mrs. Craig	Charles Fisher	75
222	1¼ miles east of Front Royal	Colonel Millar	J. M. Totten & Son	78
223	1½ miles northeast of Front Royal	Dr. Kipps	J. M. Totten & Son	327
224	2¾ miles northeast of Front Royal	Henry Compton	J. M. Totten & Son	45
225	Front Royal	Ice Plant	J. M. Totten & Son	125
226	Front Royal	Cold Storage plant	J. M. Totten & Son	87
227	Front Royal	J. Cameron	J. M. Totten & Son	48
228	1 mile east of Front Royal	Gardner Waller	J. M. Totten & Son	48
229	1¼ miles south of Front Royal	H. J. Seibell	J. M. Totten & Son	519
230	2 miles south of Front Royal	Happy Creek Mining Co	J. M. Totten & Son	80
231	Arco	Lee Burke	J. M. Totten & Son	74
232	1¾ miles south of Arco	Wash Marlow	J. M. Totten & Son	50
233	2 miles east of Browntown	J. K. Marlow	J. M. Totten & Son	28
234	Browntown	Browntown School	J. M. Totten & Son	75
235	1¾ miles southwest of Waterlick	United States Bureau of Fisheries.	J. M. Totten & Son	100
236	2½ miles south of Waterlick	Carnett Ridgeway	J. M. Totten & Son	37
237	3 miles south of Waterlick	M. C. Robinson	J. M. Totten & Son	87 107
238	4¼ miles south of Waterlick	William Hesket	J. M. Totten & Son	68
239	4¾ miles south of Waterlick	Warren County School Board	J. M. Totten & Son	100
240	2½ miles north of Limeton	H. H. Donning	J. M. Totten & Son	37
241	2 miles southwest of Bentonville	Dr. Davis	J. M. Totten & Son	287

in Warren County, Virginia

wells)

Character of material	Geologic horizon	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone	Beekmantown	4			200
Limestone	Beekmantown	10	Small	6-inch water-filled opening at bottom of well.	201
Limestone	Conococheague	1½			202
Limestone	Conococheague	13		Limestone, 30 feet "firestone", then more limestone.	203
Limestone	Beekmantown	12			204
Limestone	Beekmantown	10		Analysis on page 76.	205
Gray shale	Martinsburg	3			206
Gray shale	Martinsburg	1½			207
Shale	Martinsburg	30	Small		208
Shale	Martinsburg	10			209
Shale	Martinsburg	15			210
Shale	Martinsburg	15			
Shale	Martinsburg	5			211
Shale	Martinsburg	30	Very small	Well flowed slight amount at surface when drilled.	212
Shale	Martinsburg	12			213
Hard shale	Martinsburg	15		Sulphurous water.	214
Shale	Martinsburg	30	8	Well flowed at surface when drilled.	215
Shale	Martinsburg	10			216
Shale	Martinsburg	10			217
Shale	Martinsburg	1			218
Shale	Martinsburg	1			
Shale	Martinsburg	30			219
Limestone	Beekmantown	12			220
Limestone	Conococheague			Analysis on page 76.	221
Shale	Elbrook	30			222
Limestone	Elbrook	1			223
Limestone (dolomite)	Tomstown	10			224
Limestone	Conococheague	20		Drilling was very difficult because of boulders in the gravel above.	225
Limestone	Conococheague	20		Boulders present in the gravel.	226
Limestone	Conococheague	20			227
Limestone	Beekmantown	8			228
Limestone	Elbrook	"Unlimited"		8-foot cavern filled with water encountered at 460 to 468 feet. Water level 60 feet below surface when drilled.	229
Greenstone	Catoctin	18			230
Greenstone	Catoctin	2			231
Greenstone	Catoctin	10			232
Greenstone	Catoctin	20			233
Granodiorite	Post-Catoctin (?)	20	Small	Boulders overlie the bedrock.	234
Shale	Martinsburg	30	Very small		235
Shale	Martinsburg	15			236
Shale	Martinsburg	15			237
Shale	Martinsburg	20			
Shale	Martinsburg	18			238
Shale	Martinsburg	2			239
Shale	Martinsburg	30			240
Limestone	Conococheague	20	Very small	Water level 20 feet below surface when drilled.	241

TABLE 15.—*Analyses of ground waters from Warren County, Virginia*

(Analyst, E. W. Lohr. Parts per million. Numbers at heads of columns refer to corresponding well numbers in preceding table.)

	205	221
Silica (SiO_2)	6.8	....
Iron (Fe)	[1] 5.2	5.0
Calcium (Ca)	100	[2] 4
Magnesium (Mg)	25	....
Sodium (Na)	23	[3] 3.4
Potassium (K)	6.7	
Bicarbonate (HCO_3)	349	20
Sulphate (SO_4)	35	[2] 2
Chloride (Cl)	28	.8
Nitrate (NO_3)	49	7.1
Total dissolved solids	463	....
Total hardness as $CaCO_3$	[3] 352	18

[1] Turbid with precipitated iron when collected.
[2] By turbidity.
[2] Calculated.

PAGE COUNTY

GENERAL FEATURES

Page County has an area of 322 square miles. Its population in 1930 was 14,852. Luray is the largest community in the county, having a population of 1,459. The residents are mostly devoted to agriculture, and about three-fourths of the area is classified as farm land. The county is not highly industrialized, for there were only 27 industrial establishments, employing a total of 651 workers, in 1929. The value of the output during that year was $4,079,784.

Page County, like Warren County, lies between the Blue Ridge on the east and Massanutten Mountain on the west. It is drained by the South Fork of the Shenandoah River and its tributaries from the mountains. The floor of the valley is characterized by rolling hills, but the relief becomes greater and the hills steeper toward the northeast. Gravel deposits subdue the relief somewhat in the central and southeastern part of the county.

GEOLOGY

The arrangement of the rocks in Page County is comparatively simple. Pre-Cambrian rocks and the basal quartzites of the Cambrian make up the Blue Ridge overthrust mass. Tomstown dolomite, dipping northwestward, crops out along the overthrust fault, at the foot of the Blue Ridge. To the west, across the most populous part of the county, the successively younger formations are exposed up to the Martinsburg shale. Massanutten Mountain itself is capped by Tuscarora quartzite that dips to the northwest, and on its west side the rest of the Silurian formations and the Lower Devonian rocks are exposed. The Martinsburg shale, however, occupies an area almost as broad as all the Cambrian and Ordovician limestones together. Pleistocene (?) gravel covers many of the Cambrian and Ordovician formations along the Blue Ridge and is also abundant on the outcrop area of the Martinsburg shale, at the foot of Massanutten Mountain.

GROUND-WATER CONDITIONS

Geologic and ground-water conditions in Page County are very similar to those in Warren County. Most of the development of water supplies has been carried on in the lowlands of the county, in the belt of limestone and shale. There are fewer records of wells in the Martinsburg shale than in Warren County, probably because the outcrop area of the shale narrows considerably to the southwest, and the gravel that

overlies much of the bedrock in the east-central and southeastern parts of Page County is thicker, more widespread, and a better water-bearer.

Wells in the limestone are numerous and very satisfactory. Few yield very large quantities, but in many of them the driller's bailer extracting 16 gallons a minute could draw the water level down only slightly. No very deep or very shallow wells were reported. The depth and yield of the few wells in the shale seem to be slightly below the average for shale wells in other areas.

The presence of the gravel makes drilling very complicated. It appears to prevent the circulation of water in the upper zones of the limestone, and in many places a ferric material known as "ocher" (iron-rich silt or mud, perhaps) has been deposited or precipitated, probably in openings which once were water-bearing. This ocherous material appears in many wells at considerable depth below the upper surface of the bedrock. In other places the gravel contains fluid mud, which clogs the casing and contaminates the water unless cased off thoroughly. This mud also filters into the cavities in the limestone and ruins many of them so far as yielding water is concerned; then the hole must be reamed to a larger diameter, so that casing may be driven down through the mud. In addition boulders are frequently encountered which deflect and jam the drilling bit. On the other hand, there are some very satisfactory wells that depend entirely upon the gravel for their supply of water. The wells average about 100 feet in depth and 10 gallons a minute in yield—good wells for nearly any kind of rock. Unless a good screen is installed, however, there is danger of sediment in the water, and the water from many wells is objectionably high in iron.

Measurements made when the wells were drilled show that the water levels in Page County have a great range in depth. In the lowlands the water is reported to be as little as 17 feet below the surface, whereas in one limestone well 264 feet deep the water level was at 210 feet. Here, as in other sections of the valley, the water level appears to be nearer the surface in shale wells than in limestone wells, and its fluctuations in response to the changes in rainfall from season to season are less marked.

The water in the Paleozoic rocks is hard, and that in the shale is high in dissolved minerals. The water in the gravel is soft but likely to be high in iron.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

Luray.—Population, 1,459. Two mountain streams heading in Stony Man Mountain furnish most of the supply. The water is conducted by gravity to open earth-fill reservoirs of 3,500,000-gallon and about 6,500,000-gallon capacity. One spring, 7 miles east of the town, in the Blue Ridge, is also used. The spring is open, and its overflow is

impounded in a small concrete reservoir, half a mile below the spring, whence it is piped into the reservoir. It enters the distributing system by gravity. The pressure ranges from 75 to 125 pounds. This spring was developed in 1911 but has been used only as an emergency supply. Another spring in limestone near the city has been used also as an emergency supply by connecting it to the mains by a temporary pipe line. Water is chlorinated at the reservoir.

TABLE 16.—*Records of wells*

(All drilled

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
250	Rileyville........................	John Huffman........	Grant & Wade Turner.	....	....	223
251	3½ miles southwest of Rileyville..	Dr. Brumback........	Grant & Wade Turner.	....	....	194
252	1½ miles northwest of Luray.....	W. T. Mauck.........	W. J. Gochenour..	1920	....	230
253	Luray..........................	Bud Hudson..........	Grant & Wade Turner.	1931	....	244
254	Luray..........................	Mrs. Anna V. Strickler.	W. J. Gochenour..	1919	....	105
255	½ mile east of Luray............	Luray Orchard Co.....	W. J. Gochenour..	1919	....	264
256	1¼ miles east-southeast of Luray..	S. L. Miller...........	W. J. Gochenour..	1917	....	79
257	1½ miles west of Luray..........	Cliff Long............	Grant & Wade.... Turner.	....	....	148
258	1½ miles west of Luray..........	M. M. Hitt...........	W. J. Gochenour..	1920	....	93
259	1 mile southwest of Luray........	J. Frank Hoffman.....	W. J. Gochenour..	1917	....	57
260	1¼ miles southwest of Luray.....	J. J. Grove...........	W. J. Gochenour..	1919	Hilltop...	144
261	2¾ miles southwest of Luray.....	Gilbert Gander........	Grant & Wade Turner.	1930	....	146
262	2¾ miles southwest of Luray.....	Noah Painter.........	Grant & Wade Turner.	1930	....	150
263	2¾ miles southwest of Luray.....	Hubert Hike..........	Grant & Wade Turner.	1930	....	100
264	1¼ miles north of Stanley........	I. N. Dovel...........	W. J. Gochenour..	1917	....	169
265	1¼ miles north of Stanley........	Lester Pendergast.....	W. J. Gochenour..	1918	....	165
266	Stanley.........................	Stanley Ice Co........	W. J. Gochenour..	1920	....	277
267	Stanley.........................	Page County School Board.	Grant & Wade Turner.	1931	....	430
268	Stanley.........................	Stanley Milling Co....	W. J. Gochenour..	1918	....	264
269	1 mile south of Stanley...........	Frank Graves.........	Grant & Wade Turner.	....	....	92
270	5¼ miles west of Luray..........	Gideon Brubaker......	W. J. Gochenour..	1917	Depression in valley.	93
271	6 miles west of Luray............	W. E. Burner.........	W. J. Gochenour..	1919	Hollow...	72
272	6¾ miles west of Luray..........	Charles Duncan.......	W. J. Gochenour..	....	....	30
273	3½ miles north of Alma..........	W. M. Long..........	W. J. Gochenour..	1917	....	97
274	1¾ miles northwest of Alma......	Ambrose Rhinehart....	W. J. Gochenour..	1917	....	97
275	Alma..........................	W. A. Jenkins.........	W. J. Gochenour..	1917	....	63
276	1¾ miles west-southwest of Alma..	Mary S. Miller........	W. J. Gochenour..	1919	....	125
277	2½ miles southwest of Stanley....	Shenandoah Valley Manganese Corporation.	W. J. Gochenour..	1918	....	157

in Page County, Virginia

wells)

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone..	Beekmantown.....	....	16	Very small.	50 feet of gravel above limestone. Analysis on page 82. Well cased to 107 feet.	250
Limestone..	Beekmantown.....	....	16	Very small.	83 feet of gravel above limestone. Well cased to 108 feet.	251
Limestone..	Beekmantown.....	....	8	....	Water-bearing crevices at 78 feet (½ gallon a minute) and at 225 feet.	252
Limestone..	Conococheague....	....	15	Very small.	Clay, sand, gravel, boulders (80 to 100 feet) and mud encountered successively. Analysis on page 82. Well cased to 38 feet.	253
Gravel.....	Pleistocene (?)....	....	16	....	....	254
Limestone..	Conococheague....	....	1½	....	....	255
Limestone..	Conococheague....	55	15	....	Sandstone boulders and mud above the limestone.	256
Limestone..	Beekmantown.....	....	16	Very small.	105 feet of silt and gravel, then limestone.	257
Gravel.....	Pleistocene (?)....	40	3	....	Water at 80 feet. Below 80 feet, sand and boulders.	258
Gravel.....	Pleistocene (?)....	40	16	Very small.	....	259
Gravel.....	Pleistocene (?)....	....	16	Very small.	Boulders and mud. Mud flowed 40 feet upward in the hole and it was pumped out and cased off. Water cleared up.	260
Limestone..	Conococheague....	....	1	....	Well cased to 26 feet.	261
Limestone..	Conococheague....	....	5	....	54 feet of gravel, then limestone. Well cased to 57 feet.	262
Limestone..	Conococheague....	28	16	....	Well cased to 22 feet.	263
Limestone..	Elbrook..........	150	8	Very small.	40 feet of sandstone, 100 feet of ocher, 24 feet of limestone, 10 feet of ocher, 5 feet of limestone	264
Gravel.....	Pleistocene (?)....	75	8	....	155 feet of clay and gravel, rest white sand.	265
Limestone..	Elbrook..........	....	17	....	40 feet of sandstone, boulders, gravel and flowing mud. 224 feet of ocher, then limestone with water on top of it and in 4 crevices in it.	266
Limestone..	Elbrook..........	....	3	....	173 feet of gravel above the limestone. Well cased to 176 feet.	267
Gravel, limestone.	Pleistocene (?).... Elbrook.	210	16	Very small.	Boulders, mud, ocher to 236 feet, then limestone, some water on top of the limestone and some in it.	268
Sandstone..	Waynesboro......	....	16	Very small.	50 feet of gravel; 22 feet of shale; 20 feet of sandstone. Well cased to 70 feet.	269
Shale......	Martinsburg......	17	16	Very small.	Boulders and sandstone above the shale.	270
Shale......	Martinsburg......	....	1	....	Analysis on page 82.	271
Gravel.....	Pleistocene (?)....	10	16	Very small.	....	272
Sandstone..	Pleistocene (?)....	57	13	4	....	273
Shale......	Martinsburg......	30	2	....	Sandstone overlies the shale.	274
Limestone..	Stones River......	30	16	Very small.	Gravel overlies the limestone.	275
Cavernous limestone.	Beekmantown.....	95	1	....	Many mud seams.	276
Gravel.....	Pleistocene (?)....	60	1	....	Sandstone and very hard boulders contained the water. Perforated casing used to catch the seeps.	277

TABLE 17.—*Analyses of ground waters from Page County, Virginia*

(Analyst, E. W. Lohr. Parts per million. Numbers at heads of columns refer to corresponding well numbers in preceding table)

	250	253	271
Iron (Fe)	....	....	[1] 5.0
Calcium (Ca)	[2] 75	173	74
Magnesium (Mg)	....	44	18
Sodium and potassium (Na+K) (calculated)	4.6	31	15
Bicarbonate (HCO_3)	284	458	82
Sulphate (SO_4)	[2] 4	72	211
Chloride (Cl)	5.0	73	3.0
Nitrate (NO_3)	.0	156	.0
Total dissolved solids (calculated)	....	775	361
Total hardness as $CaCO_3$	234	[3] 613	[3] 259
Date of collection (1933)	May 10	May 10	May 10

[1] Turbid with precipitated iron when collected.
[2] By turbidity.
[3] Calculated.

ROCKINGHAM COUNTY

GENERAL FEATURES

Rockingham County has an area of 876 square miles. Its population in 1930 was 29,709. Harrisonburg is the largest community in the county, having a population of 7,232. The residents are mostly engaged in agriculture, and slightly more than half of the area is classified as farm land. The county is not highly industrialized but more so than Page, Warren, and Shenandoah counties. In 1929 there were in the county 83 industrial establishments, employing a total of 1,178 workers, and the value of the output was $5,246,442.

Most of Rockingham County lies in the Shenandoah Valley between the Blue Ridge on the east and North Mountain on the west, for Massanutten Mountain ends near the northeast border of the county. The area is drained by headwaters of the North and South forks of the Shenandoah River. Here, as in other parts of the Valley, the relief is moderate, but the topography is decidedly rolling. The large streams have cut a considerable distance below the general level of the Valley floor. West of North Mountain the topography is mountainous, with high ridges and long, narrow valleys. The relief of the floor of these valleys is greater than the relief in the Shenandoah Valley.

GEOLOGY

The arrangement of the geologic formations in the southeastern part of Rockingham County is similar to that in Page County. The axis of the Massanutten syncline is occupied by Martinsburg shale alone in

the southwest half and by the Silurian and Devonian rocks of Massanutten Mountain in the northeast half. To the east of the synclinal axis the successive formations crop out, dipping northwest. The Tomstown dolomite and basal quartzites of the Cambrian crop out along the foot of the Blue Ridge. Pre-Cambrian rocks make up the Blue Ridge overthrust sheet. The Cambrian and Ordovician limestones are partly covered by Pleistocene (?) gravel. It is in this part of the area that the gravel is most abundant.

West of the Massanutten syncline the successively older rocks, dipping eastward, crop out. The Elbrook limestone is broken by an overthrust fault of comparatively small displacement, and it is thrown into juxtaposition with the Beekmantown limestone. At the northeast border of the county, between Broadway and the Valley Turnpike, the rocks are involved in a small anticline, with the Conococheague limestone at the axis. This fold dies out just northeast of Harrisonburg, and in line with its axis to the southwest there is a small syncline whose axis is occupied by Martinsburg shale. Athens shale is exposed extensively between the northeastern nose of the syncline and the southwestern nose of the anticline, in the vicinity of Harrisonburg. Broadway is about on the axis of another small syncline that extends into Shenandoah County. Martinsburg shale crops out in the axis of this fold, which is offset to the northwest of the syncline southwest of Harrisonburg. West of these two synclines the rocks have an anticlinal trend, and older rocks crop out successively to the northwest. Elbrook limestone is broken by the North Mountain fault.

West of the North Mountain fault, in the vicinity of Brocks Gap, the rocks are sharply anticlinal, with Martinsburg shale exposed in the core. The anticline is overridden at both ends by the North Mountain overthrust mass, and it disappears about 10 miles southwest of Brocks Gap but extends into Shenandoah County. Immediately west of this anticline in the northeastern part of the county a syncline that is well developed in Shenandoah County projects a short distance into Rockingham County. Catskill rocks are exposed in its axis. Northward from Fulks Run an anticlinal fold of considerable intensity brings Silurian and Ordovician rocks to the surface. In the rest of the area west of North Mountain the beds lie nearly flat. The Catskill formation is exposed over much of the area, and in the vicinity of Rawley Springs the Pocono sandstone, of Mississippian age, crops out.

GROUND-WATER CONDITIONS

Area west of North Mountain.—Most of the wells that furnish the data in the area west of North Mountain are clustered about Fulks Run and Cootes Store, where several of the Silurian and Devonian forma-

tions crop out. No specific conclusions should be drawn as to the ground-water conditions in parts of this western area where no well records are available, but it may be assumed that the wells here recorded probably represent the general ground-water conditions.

The wells are shallow, only a very few being 100 feet or more deep. Indeed, one well drilled in Tuscarora sandstone, the "mountain flint," is only 13 feet deep. In this well a yield of 1 gallon a minute was considered sufficient, in view of the difficulty of drilling. The yield of the wells varies, but is mainly moderate to small. The best wells are in the Romney shale, but not all the wells in this formation are strong. The Cayuga and Helderberg limestones are not especially favorable sources of water—at least no better than the Romney shale. Were it not for a few wells of strong yield in the Romney shale the rocks west of Little North Mountain might be considered unpromising as a source of any but distinctly small supplies. At Rawley Springs a well on the property of H. L. Dechard is 71 feet deep and yielded at the time of drilling about 50 gallons a minute, with a 10-foot draw-down, from rocks of Catskill and Chemung age. Three wells in the Romney shale east of Fulks Run yield 25, 25, and 20 gallons a minute, and two more yield 16 gallons a minute with very slight draw-down. Outside of these six wells the average yield of wells for which data are available is not over 5 or 6 gallons a minute. No failures were reported in the 24 wells considered. The records do not indicate that a large yield, such as 50 or 100 gallons a minute, can be obtained easily in this region. However, wells of small diameter that end at the point where the first small supply is encountered do not constitute proof that large supplies are impossible to obtain.

A few records of water levels at the time of drilling indicate that the water is under some artesian head and that in rainy periods the water level may be very close to the surface. This high water level is favorable for a large draw-down, which insures efficient utilization of the potential yield of the well. It does not necessarily mean that the pumping lift will be slight.

Much of the water in this area is so high in sulphur and iron that these ingredients can be tasted or smelled. The water is likely to be soft.

Valley region.—At Timberville, in the north-central part of the county, and north and northeast of the village the records of 16 wells have been obtained. The water-bearing rock is limestone. Most of these wells are between 150 and 250 feet deep, but some are less than 100 feet and a few are a little more than 250 feet. In general the deeper wells yield more water than those less than 100 feet deep. Exceptions are the 200-foot well (343) on the property of Arthur Bushong, which yields only half a gallon a minute, and the 280-foot well (350) owned by the Zigler Brothers, which yields only 3 gallons a minute. On the other

hand, a 60-foot well on the property of Arthur Bushong yields 25 gallons a minute. The average yield of the wells in the vicinity of Timberville is about 14 gallons a minute. Two wells in this area did not reach the limestone, having been drilled where the ocherous sand, mud, and gravel of Pleistocene (?) age are especially thick. These wells (346 and 349) are respectively 60 and 70 feet deep, and each yielded 12 gallons a minute at the time it was drilled.

Water levels in the valley area are diverse, varying from place to place with the topography. In most places they are less than 100 feet below the surface.

In Broadway and westward to Brocks Gap records of 15 wells have been obtained from the drillers who put them down. All but three, which are southwest of Broadway, derive their water supplies from limestone. Most of these wells are about 100 feet deep or slightly more. A few wells are shallow, such as wells 360, 358, and 362, which are respectively 20, 40, and 42 feet deep. The largest yields are obtained from the wells of moderate depth, such as well 356, owned by the town of Broadway. It is 120 feet deep and when drilled was pumped at 100 gallons a minute. The yield of the rest of the wells is small regardless of the depth. The three wells that end in shale deliver about as much water as the ordinary limestone wells in the vicinity. The reported depth to water when the wells were drilled shows that, whereas the water level in limestone wells varies from place to place, the water level in shale wells is consistently near the surface of the ground. In fact, well 361 flowed a slight amount at the surface when it was drilled. Some of the wells in the Chambersburg limestone in Broadway yield water that contains noticeable quantities of "white sulphur," but the presence of the sulphur does not seem to impair its usefulness.

Records of 9 wells in the vicinity of Linville, Edom, and Singers Glen furnish the data for conclusions in that part of the county. All the wells end in limestone, although well 387 penetrated considerable gravel, boulders, and mud before reaching the hard rock. The wells are deeper in this locality than in some others, ranging from 60 to 305 feet, but most of them are from 100 to 200 feet deep. Their yields, as reported by the drillers, are likewise high, ranging from 4 to 25 gallons a minute and averaging 11 gallons a minute. If these reported yields are accurate and are typical of the wells in the vicinity whose records are not known, the limestone here is especially favorable as a source of consistently good well supplies. Apparently the water has no peculiar chemical characteristics, and it is probably of moderate hardness and entirely acceptable for most uses.

Records are available of 20 wells distributed along the Valley Turnpike from the Shenandoah County line to a point about 2 miles northeast of Harrisonburg. All wells draw their water from limestone or

the Athens shale, which in some places is so limy that hydrologically it seems to resemble limestone more than a typical shale. In other places the wells in the Athens shale resemble wells in the Martinsburg shale. Most of these wells are from 100 to 200 feet deep, a few between 40 and 100 feet, and one 400 feet. The yield of the wells is diverse, ranging from 125 to 1 or 2 gallons a minute. Well 374 is 125 feet deep and was reported to yield no water whatever. Most wells in limestone and shale yield from 5 to 15 gallons a minute, but a larger number of them than in most other localities yield 20, 25, to 40 gallons a minute. These wells of large yield derive their supplies from limestone; the wells in Athens shale yield from 4 to 15 gallons a minute. Well 369, which yielded 125 gallons a minute, is 160 feet deep. The water levels, as reported by the drillers at the time the wells were completed, was consistently about 30 to 40 feet below ground for wells in the limestone, and not more than 10 feet in the less calcareous parts of the Athens shale. Well 377, which was put down 40 feet into Athens shale, flowed 3 gallons a minute at the surface when the well was completed and yielded 8 gallons a minute when pumped. Flowing wells are not uncommon in areas underlain by shale, but as a rule they are not economically important, owing to the small head. A few wells in the limestone yield water that contains "white sulphur," and well 377, in the Athens shale, yields water high in iron.

The 10 wells in and near Harrisonburg of which records are available are especially interesting in that they include some of the deepest and most productive wells in the whole area studied. Of the 10 wells (391 to 400) one yields 60 gallons a minute, one 80, one 90, and two 125 gallons a minute. The two wells that yield 125 gallons a minute are 160 and 140 feet deep. The well that yields 80 gallons a minute is 520 feet deep, the one that yields 60 gallons, 1,322 feet; and the one that yields 90 gallons, 1,926 feet. The 1,926-foot well obtains all of its water above the 600-foot depth, whereas the 1,322-foot well obtained 50 gallons a minute from a 5-foot opening encountered 1,317 feet below ground. This cavity contained an "onyxlike" rock which the driller believed was a stalactite or stalagmite. The smaller wells are between 100 and 200 feet deep and yield from 2 to 12 gallons a minute. Well 396, which is 140 feet deep and yields 125 gallons a minute when pumped, flowed a small amount when it was drilled.

Records of 17 wells in the part of the county southwest of Harrisonburg and east of North Mountain are available. The wells are scattered rather widely and uniformly over this area. The greatest part of the area is underlain by limestone except where Athens shale appears at the surface. Almost all these wells are from 100 to 200 feet deep, only two being deeper than 200 feet and one less than 100 feet. The wells are moderate producers, most of them yielding 5 to 15 gallons a minute,

four wells 20 to 50 gallons a minute, and only two wells less than 5 gallons a minute. Well 329 is 110 feet deep and is dry, although it passed through about 65 feet of cavernous limestone. Well 332 yielded 50 gallons a minute when drilled. This part of the county seems to be very favorable for the development of wells in the limestone that yield more than enough water for ordinary household and farm use. In addition there is apparently a good chance for developing large supplies from wells of moderate depth. No records of water level are available, and no unusual chemical characteristics of the water were reported.

Between Harrisonburg and Keezletown there are six wells whose records are available. Their depth ranges rather uniformly between 140 and 280 feet. The yield of most of them at the time they were drilled was moderate to small. Well 416 was pumped by the driller at 25 gallons a minute, but it goes dry in droughty periods. Some of these wells are in the lowlands, and some are on the ridges and hills, so that records of water level in one may have no meaning in a consideration of the whole area. Thus well 414 is in a hollow, and the water level at the time the well was drilled was 10 feet below ground. On the ridges the water level is much deeper.

Nine wells furnish the information concerning the local ground-water conditions in the vicinity of Elkton. Most of the wells penetrate a considerable layer of Quaternary silt, sand, and gravel and then enter limestone. Well 420 is in the Martinsburg shale to the east of Elkton, near Massanutten Mountain. The wells in and very near Elkton are only moderately deep—mostly from 100 to 200 feet—and yield small to moderate supplies. Four wells yielded from 2 to 10 gallons a minute when they were drilled, but wells 424 and 426 yielded respectively 50 and 60 gallons a minute. The water obtained by well 426 was encountered at a depth of 40 feet, where the Pleistocene (?) gravel rests upon limestone. This well is no longer used. Farther south well 428 was drilled into limestone after penetrating 35 feet of gravel, but the yield was only 1 gallon a minute.

Wells are not so plentiful in the southeastern part of the county as in some other parts. The available records indicate that wells of moderate depth can be expected to yield a small quantity of water. Pleistocene (?) gravel overlies the hard-rock formations near the foot of the Blue Ridge. The best well in that part of the county of which a record is available is well 412. It is 75 feet deep, and the gravel yields 15 gallons a minute with very slight draw-down. Mud flowing into the casing was a serious problem in the finishing of this well. At the site of well 413 the gravel that overlies the limestone is not water-bearing. Measurements recorded at the time the wells were drilled indicate that the water level in the limestone wells north of the Grottoes is 50 to 80 feet below ground. The water in the gravel, as well as the water taken from lime-

stone underlying the gravel is almost certain to contain much iron—in many places an objectionable amount.

The ebbing and flowing spring near Broadway is described on pages 52-54.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

Dayton.—Population, 537. A spring system owned by J. B. Grove furnishes water for the town. The spring emerges at the bottom of an artificial lake covering about 15 acres. Water is pumped from the lake to an 18,000-gallon concrete and brick reservoir at the edge of the town. The pump line opens under hoods at the point where the spring discharges into the lake. From the reservoir water is pumped into an 80,000-gallon elevated tank. The average daily consumption since the system was put under meters is 35,000 gallons. The city of Harrisonburg pumped from 450,000 to 600,000 gallons a day from the lake during the summer of 1930, and about the same quantity for 7 weeks during the summer of 1931. The water is chlorinated at the reservoir.

Elkton.—Population, 965. Water from Kite Spring, about three-quarters of a mile east of the town, is piped by gravity to a pump house, whence it is pumped to a 1,000,000-gallon concrete reservoir on a hilltop 150 feet above the town. The pump has a capacity of 200 gallons a minute. The water passes from the reservoir to the distributing system by gravity. The average per capita consumption is 150 gallons a day, and the total average daily consumption is 121,000 gallons.

Harrisonburg.—Population, 7,232. The entire supply for this city formerly came from a spring in the valley of Dry River, 13 miles northwest of the city, with an auxiliary supply piped from a small dam on the river. The spring that furnished the chief supply issues from the valley alluvium and flows a short distance into a flume that conducts it into an intake basin. The water is brought by gravity directly to the city's distributing system. Back pressure from the system maintains the level in two open concrete reservoirs, east of the city, of 6,000,000- and 15,000,000-gallon capacity. During 1930 and 1931 a severe shortage made it necessary to pump water from the spring that supplies Dayton, at a rate of about 450,000 to 600,000 gallons a day. On the recommendation of A. C. Spencer, of the United States Geological Survey, an addition to the supply was investigated, and a ground-water cut-off wall was decided upon. This wall was to be built near the old intake and deflect the underflow of the valley into the present supply. Borings and pits showed that the rock floor of the valley was level and covered by only about 10 to 20 feet of alluvium, with a somewhat deeper trench running under the original intake stream. Pumping tests run in some of the observation

pits indicated that the alluvium was capable of carrying large amounts of ground water. A trench 900 feet long was dug directly across the valley from the dam on the river to the original spring-fed stream 1,200 feet above the intake, and a concrete wall 10 to 12 feet high was set in it, anchored soundly in the hard sandstone floor of the valley. Coarse gravel and cobbles were built up against the upstream side of the wall to conduct the underflow across the valley to the intake. Preliminary measurements indicate that about 850,000 gallons a day were added to the surface supply. It is expected that the flow during drier summers will be somewhat smaller. The average consumption in the town is about 1,000,000 gallons a day. The water is treated with chlorine at the intake. A more detailed account of the new system has been written by the engineer who installed it.[10]

Timberville.—Population, 302. A spring owned by the Timberville Water Corporation, 3 miles northwest of the town, discharges by gravity into a concrete covered reservoir 10 by 15 by 7 feet, half a mile outside of the town. The spring is protected by a concrete covered basin. The water enters the distributing system by gravity. The pressure averages 90 pounds in the lower part of the town. The water is chlorinated at the reservoir.

[10] McDaniel, A. P., Eng. News-Record, Dec. 13, 1934, pp. 757-759.

TABLE 18.—*Records of wells*

(All wells

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
300	9¼ miles north of Fulks Run	Rockingham County School Board.	J. T. Helbert			65
301	8¾ miles north of Fulks Run	S. R. Fawley	J. T. Helbert		At edge of river.	110
302	Fulks Run	Robert Miller	J. T. Helbert			65
303	Fulks Run	James Hoover	J. T. Helbert			62
304	Fulks Run	J. D. Custer	J. T. Helbert			50
305	Fulks Run	S. R. Crider	J. T. Helbert			13
306	Fulks Run	George Fulk	J. T. Helbert			40
307	Fulks Run	Laney Custer	J. T. Helbert			65
308	Fulks Run	John Fawley	J. T. Helbert			60
309	1 mile east of Fulks Run	Perry Hoover	J. T. Helbert			56 65
310	2 miles east-southeast of Fulks Run.	Clyde Trumbo	J. T. Helbert			60
311	2¾ miles east-southeast of Fulks Run.	John Trumbo	J. T. Helbert			66
312	2¾ miles east-southeast of Fulks Run.	Harl Turner	J. T. Helbert			70
313	2¾ miles east-southeast of Fulks Run.	M. C. Runion	J. T. Helbert			65
314	Cootes Store	Charles Ralls	W. J. Gochenour			45
315	1¼ miles south of Fulks Run	B. F. Turner	W. J. Gochenour			121
316	1½ miles south of Fulks Run	J. C. Turner	W. J. Gochenour			50
317	1¾ miles south of Fulks Run	Basil Cooper	J. T. Helbert			90
318	1¾ miles south of Fulks Run	J. W. Ritchie	W. J. Gochenour			50
319	1¾ miles south of Fulks Run	Mr. Sager	J. T. Helbert			55
320	1¾ miles south of Fulks Run	John Branneman	J. T. Helbert			45
321	2¾ miles south of Fulks Run	DeWitt Fulk	J. T. Helbert			55
322	1½ miles southwest of Fulks Run	Charles Einswiler	J. T. Helbert			85
323	1½ miles southwest of Fulks Run.	Solomon Fulk	J. T. Helbert			100
324	1¾ miles south-southwest of Cootes Store.	Misses Smootz	H. N. Hulvey			120
325	9¼ miles southwest of Cootes Store.	S. E. Beery	H. N. Hulvey			180
326	9¼ miles southwest of Cootes Store.	D. H. Rolston	H. N. Hulvey			80
327	10 miles southwest of Cootes Store.	John Ralston	H. N. Hulvey			110
328	Rawley Springs	Harry Lee Dechard	J. T. Helbert			71
329	3½ miles south of Rawley Springs.	Edward Garber	H. N. Hulvey			110
330	4 miles south-southeast of Rawley Springs.	Irving Coogler	J. T. Helbert			75
331	4½ miles south of Rawley Springs.	C. H. Beam	H. N. Hulvey			110
332	¾ mile west of Spring Creek	Wine Brothers	J. T. Helbert			170
333	¾ mile west of Spring Creek	Herbert Patterson	J. T. Helbert			160
334	1½ miles southeast of Spring Creek.	Elmer Miller	J. T. Helbert			265
335	1½ miles east of Spring Creek	Herbert Patterson	J. T. Helbert			140
336	4¾ miles north of Timberville	William Miller	J. T. Helbert			65
337	3 miles north-northwest of Timberville.	Zigler Brothers	J. T. Helbert		Hollow	105
338	3 miles north-northwest of Timberville.	Zigler Brothers	J. T. Helbert		Foot of ridge.	200
339	3 miles north-northwest of Timberville.	Harry F. Byrd	J. T. Helbert			265

in Rockingham County, Virginia

drilled)

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale......	Brallier..........	....	10	....	Analysis on page 98. Contains "white sulphur."	300
Shale......	Chemung.........	....	3	....	....	301
Limestone..	Helderberg.......	....	6	....	....	302
Limestone..	Helderberg.......	....	6	....	Analysis on page 98.	303
Limestone..	Cayuga..........	....	10	....	....	304
"Mountain flint".	Tuscarora........	....	1	....	Rock was so hard it took 10 days to drill 13 feet.	305
"Mountain flint".	Tuscarora........	....	2	....	40 feet of shale overlaying the "mountain flint"; a charge of dynamite brought water to the dry hole. Analysis on page 98.	306
Shale......	Clinton..........	....	5	....	H_2S in the water.	307
Shale......	Clinton..........	....	10	....	H_2S in the water.	308
Shale......	Romney..........	....	20	....	H_2S in the water.	309
Shale......	Romney..........	....	25			
Shale......	Brallier..........	....	10	....	....	310
Shale......	Brallier..........	....	6	....	H_2S in the water.	311
Shale......	Romney..........	....	10	....	H_2S in the water.	312
Shale......	Romney..........	....	25	....	H_2S in the water.	313
Limestone..	Elbrook..........	2	16	Very small.	....	314
Shale......	Romney..........	....	1	....	....	315
Shale......	Romney..........	....	16	Very small.	....	316
Shale......	Romney..........	....	4	....	....	317
Shale......	Romney..........	....	16	Very small.	....	318
Shale......	Romney..........	....	6	....	Water strong in iron oxide.	319
Shale......	Romney..........	....	5	....	Water strong in iron oxide.	320
Shale......	Romney..........	....	6	....	Not much iron.	321
Shaly limestone.	Elbrook..........	....	2	....	....	322
Shaly limestone.	Elbrook..........	....	1½	....	....	323
Shaly limestone.	Conococheague....	....	3	....	....	324
Shaly limestone.	Elbrook..........	....	10	....	....	325
Shaly limestone.	Elbrook..........	....	8	....	....	326
Shaly limestone.	Conococheague....	....	4	....	....	327
Sandstone, black shale.	Catskill.......... Chemung.	10	50	10	65 feet of Catskill sandstone overlying the Chemung shale, Analysis on page 98.	328
Limestone..	Elbrook..........	....	0	....	43 feet of soil above the limestone. Limestone cavernous but dry.	329
Limestone..	Conococheague....	....	10	Small..	Driller estimates the yield at 30 gallons a minute.	330
Limestone..	Elbrook..........	....	2	....	Soil overlies the limestone.	331
Limestone..	Elbrook..........	....	50	....	....	332
Limestone..	Elbrook..........	....	10	....	....	333
Limestone..	Beekmantown.....	....	8	....	....	334
Limestone..	Beekmantown.....	....	7	....	....	335
Shaly limestone.	Elbrook..........	....	3	....	....	336
Shaly limestone.	Conococheague....	....	5	....	Water used for washing and for spraying orchard.	337
Shaly limestone.	Conococheague....	....	20	....	Water used for washing and for spraying orchards.	338
Shaly limestone.	Conococheague....	....	12	....	Water used for washing and for spraying orchard.	339

TABLE 18.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
340	2¾ miles northwest of Timberville.	George W. Sager......	J. T. Helbert.....	....	....	210
341	2 miles northwest of Timberville...	Gene Andrick.........	J. T. Helbert.....	....	Low ground near stream.	40
342	1¾ miles northwest of Timberville.	Lester Garber.........	J. T. Helbert.....	....	Side of ridge half way to top.	165
343	1½ miles north-northeast of Timberville.	Arthur Bushong.......	J. T. Helbert.....	....	....	200 60
344	3¼ miles east of Timberville......	Charles Doll..........	J. T. Helbert.....	....	....	149
345	3¼ miles east of Timberville......	Henry Henkel.........	Grant & Wade Turner.	....	....	175
346	3¼ miles east of Timberville......	David Smucker.......	J. T. Helbert.....	....	....	60
347	1½ miles east-northeast of Timberville.	Pence Brothers........	J. T. Helbert.....	....	Top of ridge.	208
348	1¼ miles northeast of Timberville.	Harry F. Byrd........	J. T. Helbert.....	....	....	240
349	1 mile east of Timberville........	Charles Smucker......	J. T. Helbert.....	....	....	70
350	Timberville.....................	Zigler Brothers.......	J. T. Helbert.....	....	Bank of Shenandoah River.	280
351	Timberville.....................	Chapin-Saks Co. Creamery................	J. T. Helbert.....	....	High on river bank.	180
352	1¼ miles southeast of Timberville.	John F. Driver........	W. J. Gochenour..	....	....	79
353	Broadway......................	D. O. Hulvey.........	J. T. Helbert.....	....	....	110
354	Broadway......................	R. L. Shuler..........	J. T. Helbert.....	....	....	165
355	Broadway......................	J. T. Helbert.........	J. T. Helbert.....	....	....	85
356	Broadway......................	Town of Broadway....	J. T. Helbert.....	....	....	120
357	Broadway......................	Town of Broadway....	J. T. Helbert.....	....	....	110
358	Broadway......................	I. P. Wittig...........	J. T. Helbert.....	....	....	40
359	Broadway......................	J. J. Pennybacker.....	J. T. Helbert.....	....	....	125
360	¾ mile west of Broadway........	Emmanuel Hoover....	W. J. Gochenour..	....	....	20
361	2½ miles southwest of Broadway..	J. C. Myers...........	H. N. Hulvey.....	....	....	60
362	1¾ miles north of Linville........	Bert Liskey...........	J. T. Helbert.....	....	....	42
363	Linville........................	Linville Lime Works...	H. N. Hulvey.....	....	....	160
364	2¼ miles southeast of Broadway..	T. O. Lambert........	Grant & Wade Turner.	....	....	76
365	2¼ miles southeast of Broadway..	Sallyards.............	Grant & Wade Turner.	....	....	87
366	7¼ miles northeast of Lacey Spring.	Casper Funkhouser....	Grant & Wade Turner.	May, 1929	....	55
367	6¾ miles northeast of Lacey Spring.	Bill Williamson.......	J. T. Helbert.....	....	....	100
368	6¾ miles northeast of Lacey Spring.	Kaiser Price..........	J. T. Helbert.....	....	....	180
369	6 miles northeast of Lacey Spring..	W. S. Kilmer.........	J. T. Helbert.....	....	....	160

Rockingham County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shaly limestone.	Conococheague....	....	5	....	....	340
Shaly limestone.	Conococheague....	....	25	Very small.	"Marl" overlying limestone. Yield estimated at 100 gallons a minute.	341
Limestone..	Beekmantown.....	....	4	....	....	342
Limestone..	Athens...........	....	½	....	Deep well shot with 250 pounds of dynamite without increasing its yield.	343
Shale......	Athens.		25			
Limestone..	Conococheague....	....	15	....	Cavernous limestone; openings filled with mud below 65 feet.	344
Limestone..	Conococheague....	160	15	Very small.	Well cased to 24 feet.	345
Boulders and mud.	Pleistocene (?)....	....	12	....	....	346
Shaly limestone, pure limestone.	Beekmantown.....	....	5	....	....	347
Limestone..	Beekmantown.....	....	20	....	....	348
Boulders and mud.	Pleistocene (?)....	....	12	....	....	349
Limestone..	Stones River......	....	3	....	....	350
						351
Limestone..	Stones River......	....	15	Moderate.	Limestone cavernous.	
Limestone..	Beekmantown.....	39	16	Very small.	Two mudseams encountered; cased with perforated casing.	352
Limestone and 5 feet of white porous rock at bottom.	Chambersburg....	....	5	....	Contains "white sulphur".	353
Limestone..	Chambersburg....	....	4	....	....	354
Limestone..	Chambersburg....	....	2	....	Contains "white sulphur."	355
Limestone..	Chambersburg....	....	100	....	....	356
Limestone..	Chambersburg....	....	3	....	Analysis on page 98.	357
Limestone..	Chambersburg....	....	4	....	....	358
Shale......	Athens...........	....	6	....	Limestone lay beneath shale, water in lower part of shale.	359
Limestone..	Chambersburg....	Flowed	3	....	Only 7 feet of limestone below the soil. Flowed when drilled.	360
Shale......	Martinsburg......	....	9	....	....	361
Shale......	Martinsburg......	4	10	....	....	362
Limestone..	Chambersburg....	....	10	....	40 feet of non-water-bearing Martinsburg shale.	363
Limestone..	Conococheague....	....	16	Very small.	....	364
Limestone..	Conococheague....	....	16	Very small.	....	365
Limestone..	Chambersburg....	10	1	....	Well cased to depth of 24 feet.	366
Limestone..	Chambersburg....	....	10	....	100 feet of shale overlying the limestone; water came in just below the contact.	367
Shale Limestone.	Martinsburg Chambersburg.	....	10	....	1 gallon a minute in the shale; rest of of the water came from the limestone.	368
Limestone, white sandstone.	Chambersburg....	....	125	....	8-inch diameter. Water in sandstone contains "white sulphur".	369

TABLE 18.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
370	5¼ miles northeast of Lacey Spring.	Huffman & Roller	W. J. Gochenour	1909	....	196
371	3¾ miles northeast of Lacey Spring.	Charles H. Zigler	Grant & Wade Turner.	1927	....	172 86
372	3¾ miles northeast of Lacey Spring.	Rockingham County School Board.	J. T. Helbert	....	....	85
373	2½ miles northeast of Lacey Spring.	Reuben Myers	J. T. Helbert	....	....	140
374	1½ miles northeast of Lacey Spring.	J. S. Sellers	J. T. Helbert	....	....	125
375	¾ mile northeast of Lacey Spring.	Bud Neff	J. T. Helbert	....	....	80
376	Lacey Spring	Kenneth Higgs	Grant & Wade Turner.	....	....	72
377	1¼ miles southwest of Lacey Spring.	Richard Long	J. T. Helbert	....	....	40
378	1⅓ miles southwest of Lacey Spring.	Virginia Prison Guard.	J. T. Helbert	....	....	158
379	1⅓ miles southwest of Lacey Spring.	Virginia Caverns Co.	J. T. Helbert	....	....	400
380	2¼ miles southwest of Lacey Spring.	Jacob Sellers	J. T. Helbert	....	....	70
381	2½ miles southwest of Lacey Spring.	Charles Armetrout	J. T. Helbert	....	....	65
382	3 miles southwest of Lacey Spring.	Dr. John Myers	J. T. Helbert	....	....	163
383	4 miles southwest of Lacey Spring.	Henry Armetrout	J. T. Helbert	....	....	265
384	4½ miles south-southwest of Lacey Spring.	Henry Armetrout	J. T. Helbert	....	....	89
385	3 miles east of Harrisonburg	Samuel Earman	J. T. Helbert	....	....	187
386	7½ miles north of Harrisonburg	D. H. Atcheson	H. N. Hulvey	....	....	60
387	7 miles north of Harrisonburg	Daniel Sanger	H. N. Hulvey	....	Hilltop	235
388	5¼ miles north of Harrisonburg	Edom Creamery	H. N. Hulvey	....	....	305
389	5¼ miles north of Harrisonburg	John Myers	H. N. Hulvey	....	....	60
390	3½ miles north-northeast of Harrisonburg.	Bert Liskey	J. T. Helbert	....	....	140
391	1¼ miles northeast of Harrisonburg.	Bert Liskey	J. T. Helbert	....	....	133
392	1¼ miles northeast of Harrisonburg.	Bert Liskey	J. T. Helbert	....	....	185
393	1¼ miles northeast of Harrisonburg.	Bert Liskey	J. T. Helbert	....	....	147
394	Harrisonburg	Valley Virginia Cooperative Milk Producers' Association.	J. T. Helbert	....	....	520
395	Harrisonburg	Imperial Ice Cream Co.	J. T. Helbert	....	....	160
396	Harrisonburg	Rockingham Motor Co.	J. T. Helbert	....	....	140
397	Harrisonburg	Cassco Ice Co	C. E. Wine and J. T. Helbert.	1922	....	1,322
398	Harrisonburg	Stehli Silk Corporation.	J. T. Helbert	1926	....	1,926
399	¾ mile southwest of Harrisonburg.	Samuel Totten	J. T. Helbert	....	Ridgetop.	105
400	1½ miles southwest of Harrisonburg.	Mount Pleasant School.	J. T. Helbert	....	Hilltop	160
401	1¼ miles northeast of Dayton	Wanger	J. T. Helbert	....	....	200
402	1½ miles northwest of Dayton	Webster Rhode	H. N. Hulvey	....	....	300

Rockingham County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone..	Chambersburg....	40	2	....	2 streams in limestone. Lower stream contains "white sulphur".	370
Shale......	Martinsburg......	30	4	....	....	371
Limestone..	Chambersburg....	30	16	Very small.		
Limestone..	Chambersburg....	....	6	....	....	372
Limestone..	Chambersburg....	....	4	....	....	373
Limestone..	Chambersburg....	....	0	....	....	374
Shale......	Athens...........	....	6	....	....	375
Shale......	Athens...........	....	16	....	Analysis on page 98. Well cased to 30 feet.	376
Shale......	Athens...........	Flowed	8	....	Flowed 3 gallons a minute. Contains much iron.	377
Limestone..	Stones River......	....	20	....	....	378
Limestone..	Stones River......	....	40	....	....	379
Shale......	Athens...........	....	5	....	....	380
Shale......	Athens...........	....	6	....	....	381
Limestone..	Stones River......	....	2	....	....	382
Shaly limestone.	Beekmantown.....	....	3	....	....	383
Shaly limestone.	Beekmantown.....	....	2	....	....	384
Limestone..	Beekmantown.....	....	20	....	At 125 feet encountered a layer of very hard "emery".	385
Limestone..	Stones River......	....	25	....	....	386
Boulders, limestone.	Pleistocene (?).... Beekmantown.	....	6	....	....	387
Shale......	Martinsburg......	....	15	....	Analysis on page 98.	388
Shale......	Martinsburg......	....	15	....	....	389
Limestone..	Stones River......	....	6	....	....	390
Limestone..	Stones River......	....	2	....	....	391
Limestone..	Stones River......	....	10	....	....	392
Shale, limestone.	Athens...........	....	12	....	Limestone at 80 feet.	393
Limestone..	Athens...........	....	80	....	....	394
Limestone..	Athens...........	....	125	Small..	....	395
Limestone..	Athens...........	Flowed	125	Moderate.	Flowed when drilled.	396
Limestone..	Athens...........	....	60	400	10 gallons a minute at 60 feet, no more water until drilling reached 1,317 feet; 5-foot opening at that depth, containing onyxlike rock believed by the driller to be broken stalactites. Analysis on page 98.	397
Shale, shaly limestone, limestone.	Athens...........	Flowed	90	....	No water below 600 feet. 45 gallons a minute of the total yield of 90 gallons a minute was cased off. Flowed when drilled.	398
Shale......	Martinsburg......	....	12	....	....	399
Shale......	Martinsburg......	....	10	....	....	400
Limestone	Stones River......	....	7	....	Well was nearly a failure until 4 shots of dynamite (totaling 225 pounds) brought in the water. Each shot brought more water.	401
Shaly limestone.	Beekmantown.....	....	4	....	....	402

TABLE 18.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Depth (feet)
403	2 miles west of Dayton	J. T. Helbert	J. T. Helbert			80
404	Bridgewater	Bridgewater Creamery	J. T. Helbert			160
405	1¾ miles southwest of Bridgewater.	G. E. Miller	J. T. Helbert			120
406	1¾ miles south of Bridgewater	J. W. Miller	J. T. Helbert			138
407	3¼ miles north-northeast of Mount Crawford.	J. L. Miller	J. T. Helbert			120
408	2¾ miles north-northeast of Mount Crawford.	Peachy Wenger	J. T. Helbert			180
409	1¾ miles north-northeast of Mount Crawford.	N. Early	J. T. Helbert			196
410	3 miles northeast of Mount Crawford.	Rockingham County Farm.	J. T. Helbert			135
411	5¼ miles east of Mount Crawford.	Charles Mundy	H. N. Hulvey			37
412	2½ miles north of Grottoes	Mr. Norford	H. N. Hulvey			75
413	¾ mile northwest of Grottoes	M. L. Wine	W. H. Hicks			110
414	1½ miles southeast of Harrisonburg.	Hirsh Brothers	J. T. Helbert		Hollow	280
415	2½ miles southeast of Harrisonburg.	Dr. D. H. Dyreley	J. T. Helbert			140
416	2½ miles southeast of Harrisonburg.	Spottswood Country Club.	J. T. Helbert			160
417	3¼ miles southeast of Harrisonburg.	Henry Wickersham	J. T. Helbert		Ridgetop.	195
418	3¼ miles southeast of Harrisonburg.	Thompson & Dinkeldine.	J. T. Helbert			210
419	4½ miles southeast of Harrisonburg.	Dinkeldine Orchard	J. T. Helbert			195
420	5 miles west of Elkton	Charles Hammer	J. T. Helbert			80
421	4¼ miles north of Elkton	Mrs. Kite	J. T. Helbert			107
422	1¼ miles northwest of Elkton	Henry Miller	J. T. Helbert			163
423	1¼ miles northwest of Elkton	Wilmer Miller	J. T. Helbert			205
424	Elkton	Elkton Tannery (now burned down).	J. T. Helbert			110
425	Elkton	R. J. Coner	J. T. Helbert			105
426	Elkton	A. N. Gooden	J. T. Helbert			60
427	1¼ miles southwest of Elkton	Samuel Hensley	J. T. Helbert		River bank.	126
428	6 miles southwest of Elkton	Mrs. Walker	H. N. Hulvey			113
429	3¼ miles east of Grottoes	V. Steere	H. N. Hulvey			88

Rockingham County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone..	Beekmantown.....	....	20	....	....	403
Limestone..	Beekmantown.....	....	30	....	....	404
Limestone..	Beekmantown.....	....	10	Very small.	Total yield estimated at 25 gallons a minute.	405
Limestone..	Chambersburg....	....	12	....	....	406
Limestone..	Chambersburg....	....	15	....	....	407
Limestone..	Chambersburg....	....	10	....	....	408
Limestone..	Chambersburg....	....	15	....	....	409
Limestone..	Beekmantown.....	....	.10	....	....	410
Shale......	Athens...........	....	4	....	....	411
Boulders and mud.	Pleistocene (?)....	50	15	Very small.	Mud flowed into casing and had to be cleared by filling casing with gravel.	412
Limestone..	Conococheague....	80	10	....	Limestone overlain by ocher, clay, and boulders which were not water-bearing.	413
Shaly-lime-stone.	Beekmantown.....	10	3	....	....	414
Shaly lime-stone.	Beekmantown.....	....	8	....	....	415
Shaly lime-stone.	Beekmantown.....	....	25	....	Dries up.	416
Shaly lime-stone.	Beekmantown.....	....	3	....	....	417
Shaly lime-stone.	Elbrook..........	....	10	....	....	418
Shaly lime-stone.	Conococheague....	....	10	....	Analysis on page 98.	419
Shale......	Martinsburg......	....	5	....	....	420
Limestone..	Conococheague....	....	8	....	....	421
Limestone..	Conococheague....	....	7	....	....	422
Limestone..	Conococheague....	....	2	....	....	423
Limestone..	Elbrook..........	....	50	....	....	424
Gravel, limestone.	Pleistocene (?).... Elbrook.	....	10	....	60 feet of gravel.	425
Limestone..	Elbrook..........	....	60	....	Water came in at bottom of gravel at 40 feet. Analysis on page 98.	426
Llmestone..	Elbrook..........	....	10	....	....	427
Limestone..	Elbrook..........	....	1	....	35 feet of sand, silt, and boulders.	428
Sand and boulders.	Pleistocene (?)....	....	2	....	Analysis on page 98. Contains much iron.	429

TABLE 19.—*Analyses of ground waters from Rockingham County, Virginia*

(Analyst, E. W. Lohr. Parts per million. Numbers at heads of columns refer to corresponding well numbers in preceding table.)

	300	303	306	328	357	376	388	397	419	426	429
Silica (SiO_2)	23	....	9.2	3.6	6.6	....	....	....	....	....	....
Iron (Fe)	.01	....	2.2	2.0	.12	....	0.66	1.6	....	....	[3] 4.8
Calcium (Ca)	20	[1] 40	38	1.2	144	149	[1] 50	[1] 1	[1] 45	[1] 34	[1] 12
Magnesium (Mg)	7.1	....	4.1	.8	20	4.6	....	....	....	....	....
Sodium (Na)	46	[2] 15	2.3	1.1	40	[2] 2.5	[2] 7.7	....	[2] 3.7	[2] 6.8	[2] 17
Potassium (K)	.7		2.1	.9	5.9						
Bicarbonate (HCO_3)	162	109	92	7.0	328	367	120	5.0	271	116	37
Sulphate (SO_4)	3.3	[1] 12	29	3.5	147	[1] 15	68	[1] 3	[1] 8	[1] 4	[1] 8
Chloride (Cl)	32	13	3.5	.5	63	12	19	.8	1.4	8.0	8.0
Nitrate (NO_3)	.0	37	9.8	.0	26	78	16	.0	4.6	30	46
Total dissolved solids	213	....	151	17	643	[2] 442	....	....	....	....	....
Total hardness as $CaCO_3$	[2] 79	117	[2] 112	[2] 6.3	[2] 442	[2] 391	192	(4)	228	120	51
Date of collection (1933)	May 10	May 10	May 10	May 10	May 10	May 10	May 10	May 10	May 10	May 9	May 9

[1] By turbidity.
[2] Calculated.
[3] Turbid with precipitated iron when collected.
[4] Less than five parts.

AUGUSTA COUNTY

GENERAL FEATURES

Augusta County has an area of 1,006 square miles. Its population in 1930 was 38,163. The city of Staunton is the largest community in the county, having a population of 11,990. Waynesboro ranks second, with 6,226 inhabitants, most of whom settled there since 1920. Most of the residents are engaged in agriculture, and slightly over half of the county is classified as farm land. The county is more highly industrialized than any other county in the area. Most of the establishments are concentrated in Staunton and Waynesboro, but Waynesboro is the only truly industrial community. In 1929 there were 88 industrial establishments in the county, employing a total of 2,219 workers, and the value of the output was $9,559,250.

Augusta County, the second largest in the State, includes the entire width of the Shenandoah Valley from the Blue Ridge to North Mountain. West of North Mountain the country is cut up into several intermontane valleys of rather rugged relief. Chief of these is the valley of the Calf Pasture River.

Part of the floor of the Shenandoah Valley in Augusta County has rather more relief than the area farther northeast. This is especially true of the northern and western parts of the county, but between Staunton and Waynesboro the relief is considerably less. Augusta County lies mostly in the headwater region of the Shenandoah River, but the southwestern part is drained by tributaries of the James River.

GEOLOGY

East of the Staunton fault, which roughly divides the county into halves, the structure of the rocks is controlled by the strongly developed Massanutten syncline. Elbrook limestone dipping southeastward is exposed immediately east of the fault. Successively younger rocks are exposed from the fault eastward to the core of the fold, which is occupied by Martinsburg shale. The fold plunges, however, just north of Greenville, and the compression in the rocks that the fold represents is taken up from Greenville southwest by the Pulaski overthrust fault. This fault throws Conococheague limestone into juxtaposition with Stones River limestone. East of the axial line of the Massanutten syncline the successively older limestones of Cambrian and Ordovician age, dipping northwest, crop out toward the Blue Ridge. The basal quartzites of the Cambrian occupy a broad outcrop area along the sides and at the foot of the Blue Ridge except near Waynesboro, where a projection of the Blue Ridge overthrust mass covers them. Gravel has been widely

deposited in this part of Augusta County and covers most of the rocks of Cambrian age.

West of the Staunton fault the structure of the rocks is dominated by a syncline whose core is occupied by Martinsburg shale near the Rockingham County line and successively by the Athens shale and Beekmantown limestone toward the southwest. The syncline dies out north of Middlebrook, and an anticline is developed to the southwest in line with its axis. Elbrook limestone makes up the core of the anticline. This same outcrop of the Elbrook limestone trends northward and then northeastward, around the syncline, so that the North Mountain fault cuts Elbrook limestone over most of its length in the county.

West of the North Mountain fault the structure is simpler. South of Buffalo Gap and east of Augusta Springs and Craigsville the Beekmantown and younger rocks of Ordovician and Silurian age crop out, dipping toward the northwest. The controlling structural feature immediately west of North Mountain is a syncline that plunges northeastward, so that Chemung, Catskill, and Pocono rocks occupy the axis successively from southwest to northeast. The syncline extends into Rockingham County. An intense anticline appears on a line between West Augusta and Deerfield, plunging northward. Silurian rocks are exposed in the core of this anticline. Except for the syncline the folds west of North Mountain are rather poorly developed and the rocks do not dip steeply except in small local folds.

GROUND-WATER CONDITIONS

Area west of North Mountain.—The wells in the part of the county west of North Mountain that furnish the records used in this discussion draw their water from the Helderberg limestone, Romney shale, and Brallier shale. What is said here, therefore, does not necessarily hold for the areas underlain by the Chemung and Catskill formations, although in the plateau region in other counties these Upper Devonian shales and sandstones are similar to the Romney and Brallier shales in their water-bearing properties.

Water in small or moderate quantities may be expected in this area at moderate depths. Water in the shale and sandstone of this area is related less to depth than water in limestone. Although in limestone a depth may be reached below which water-bearing crevices are rare or absent, in the Devonian shale and sandstone most wells will continue to encounter water-bearing crevices or beds as deep as they are drilled. Some wells 100 feet deep or less yield 5 gallons a minute, but if they had been drilled to 300 feet they might have been far more productive. It happens that most wells in the region west of North Mountain are drilled for domestic supplies, and a small yield is enough.

Wells in the western part of Augusta County differ greatly in depth, but most of them are less than 100 feet deep. Two wells are 30 feet deep or less, two between 30 and 40 feet, two between 60 and 70 feet, and the remaining five wells from 117 to 850 feet. In general the shallower wells yield less water than the deeper, but the rule has exceptions. Thus, the wells less than 100 feet deep yield on an average of 6 gallons a minute, whereas all wells over 100 feet deep yield an average of 15 gallons a minute. Well 509 is 850 feet deep and yields about a pint of water a minute, when pumped. A supply of 10 gallons a minute was encountered at 22 feet, but this water was cased off by order of the owner, and drilling was continued with very little success. On the other hand, well 508 is 450 feet deep, and its yield was tested at 34 gallons a minute. In Highland County, just west of Augusta County, well 452 was drilled into Helderberg limestone, and although apparently isolated pockets of water were encountered the net yield after 305 feet of drilling was nothing. In general water is easy and cheap to get in this part of Augusta County. The water level in wells in the lowlands and lower slopes is very close to the surface—less than 15 feet deep in most places—and flowing wells are not uncommon. Well 507 is on a slope and is higher than the house. It flows so that the trickle of water can be piped to the house like a spring. The water in this area is highly mineralized and moderately hard, and in many localities the odor of hydrogen sulphide is noticeable in freshly pumped water.

Valley region.—Records of 11 wells drilled into limestone between Churchville and Mount Solon were made available by the drillers. Most of these wells are between 125 and 200 feet deep, but three are less than 100 feet. The yield of these wells is mostly between 5 and 10 gallons a minute. Four wells deliver less than 5 gallons a minute, and one (510) yields 50 gallons a minute. As might be expected in a limestone terrane, there is no strict relation between depth of well and yield of water. All the wells that deliver 5 gallons a minute or less are from 100 to 200 feet deep, whereas all the shallow wells in this group yield from 8 to 10 gallons a minute. On the other hand, the deepest well of the group yields the greatest amount of water. No significant information was at hand as to the depth of water below ground in this area, but because the topography is rolling and the bedrock is limestone, the water level is probably deep on the hills—100 to 200 feet in some places—and shallow in the lowlands.

The records of 27 wells drilled in the triangular area bounded by Churchville, Buffalo Gap, and Staunton but not including the city of Staunton indicate that the limestone, which underlies most of it, is neither more nor less satisfactory as a source of water than the limestone in other parts of the Shenandoah Valley. Some of the wells have obtained

good supplies at small depths, and some have encountered but little water at great depths, but most wells are of moderate depth and deliver adequate supplies for farm or household needs. Most of these wells are between 100 and 250 feet deep, and yield, on an average, a little less than 10 gallons a minute. Well 552 is the shallowest one of the group (59 feet) and delivers 20 gallons a minute, which is as much as any other well in this group is reported to yield. Well 544 is the deepest (796 feet) and yields 1½ gallons a minute, almost as little as any other in the group. It was reported that the owner blasted the well and increased its yield somewhat, but the exact amount is not known. Well 573 is 536 feet deep and yielded about 6½ gallons a minute when it was completed. Two wells, each about 130 feet deep, went dry and were redrilled to a greater depth. One of these wells weakened seriously again in 1932. Shallower wells in the same area have survived all droughts. Two other wells were drilled into limestone that contained mud-filled cavities. These mud seams are very annoying to both the drillers and the owners, because the hole must be reamed and casing inserted. The owner of well 524 has reported that the water from this well is soft. This report could not be substantiated nor disproved. In some places the water level is as much as 180 feet below the ground, but in the valleys the water level is considerably shallower.

Records of six wells in the area southwest of Staunton extending to the vicinity of Middlebrook indicate that results of drilling in the local limestone terrane are somewhat more favorable than in some other parts of the Shenandoah Valley. Each of the two wells less than 100 feet deep (526 and 527) yields more than any one of the deeper wells. The deepest well yields the least water of all but one. If these six wells are typical of other wells whose records are not available the area is especially favorable for wells of moderate depth—less than 150 feet. For the area southwest of Middlebrook to the Rockbridge County line there are no records of wells, and consequently it is not possible to say that the area is as favorable as that northeast of Middlebrook.

Records of wells in the north-central part of Augusta County, from Burketown to Grand Cavern and south of Fort Defiance, show more diversity in the results of drilling than wells in the western limestone belt. Of the ten wells of which records are available eight are between 50 and 200 feet deep and yield from less than 1 gallon to 30 gallons a minute. Most of the wells deliver less than 10 gallons a minute. Well 599 is 46 feet deep and was drilled in Martinsburg shale. Contrary to the usual results of drilling in this shale, only half a gallon a minute was obtained. A hole put down nearby 155 feet into the shale encountered no water. There seems to be but little difference in yield between wells drilled in limestone and wells drilled in shale in this area. Most of the limestone wells are deeper than the shale wells. In general, the available

records show that the risk of obtaining insufficient water for ordinary farm or household use is greater in this area than in many other parts of the county. At the same time well 593 delivers 30 gallons a minute from the Athens shale.

Records of the wells drilled in the city of Staunton, which are some of the most significant wells in the county, were obtained from the driller. Although most of the 13 wells were drilled to furnish ordinary household supplies, three of them were put down to obtain large supplies. The deepest one is well 560, 1,400 feet deep. During the course of drilling this well a cavity 60 feet deep was passed through at about 600 feet. This cavity contained no water, and it is reported that most of the 40 gallons a minute the well yields came in below 600 feet. Well 563 is 801 feet deep and delivered 140 gallons a minute when finished. Of this only 6 gallons a minute came in above 790 feet. Well 564 is 689 feet deep and yields 20 gallons a minute. The well records show that in some places deep drilling brings in more water than is obtained from shallow or moderately deep wells. Other deep wells, however, do not obtain unusually large supplies. For instance, the 1,400-foot well yields 40 gallons a minute, the 689-foot well yields 20 gallons a minute, but well 565 is only 250 feet deep and yields 30 gallons a minute, and well 566 is 66 feet deep and delivers 20 gallons a minute. Most of the other wells, of small to moderate depth, yield from 15 down to 2 gallons a minute. Well 562 is interesting because drilling in other wells near the National Cemetery has shown similar results. After many difficulties this well was put down through 35 feet of clay, then "broken" limestone to a depth of 350 feet. The yield was less than a quart a minute. Wells nearby were likewise unsuccessful, and in fact the clay continued to a depth of 120 feet in some places. Aside from this one locality the prospects in and near Staunton are excellent for small or moderate supplies of water at moderate depths and fair for large supplies at great depth. Measurements of the water level in limestone wells taken at random times are of very little value, but two readings are available that indicate the order of magnitude of the static level in the district. In well 563 the water was 24 feet below ground when it was completed, and in well 562 at 80 feet.

The ground-water conditions east of Staunton and west of Fishersville in the area extending northeastward from Mint Spring, are illustrated by the records of 13 wells. Part of these wells are in limestone and part in shale. Most of the wells are shallow or moderately deep, only two being more than 180 feet. Yields are small, 8 of the 13 wells delivering not more than 5 gallons a minute, and the rest less than 15 gallons a minute. Strangely the results of drilling in the shale are better than those in the limestone, for the shale wells are shallower and

yield more water on the average, and their yields depart less from the average yield.

Wells in the area southwest of Mint Spring, including Greenville, Spottswood, and Steele's Tavern, are in limestone. Most of them are shallow and yield uncommonly large supplies. In fact, if the eight wells of which records are available typify conditions in this area, it is extremely favorable for the development of moderately large supplies at slight depth. Five of the eight wells are less than 100 feet deep and yield on the average 13½ gallons a minute, whereas the average yield of the deeper wells is less than 10 gallons a minute. The well that yields most water (23 gallons a minute) is only 47 feet deep; the deepest well delivers only half a gallon a minute. This does not necessarily mean that shallow wells are better than deep wells; rather the records indicate that sufficient water was obtained at shallow depths and that drilling was stopped. If some well like well 535 were drilled 200 or 300 feet deeper it might deliver a much larger quantity of water. Water-level measurements taken at the time the wells were finished show that in most of this area the water stands within 20 feet of the ground (when the wells are not affected by pumping). One striking exception is well 537, which is 365 feet deep and yields half a gallon a minute and in which the water level was reported to stand at a depth of 250 feet.

Ground-water conditions in the part of the county north of Fishersville and Waynesboro and east of Christian Creek and the Middle River are represented by only five wells. Obviously, conclusions as to this area must be made sparingly, especially in view of the different types of rock in the area, the gradual increase in relief eastward toward the Blue Ridge, and the presence of Pleistocene (?) gravel overlying the water-bearing formations in the eastern part of the area. The available information indicates that the results of drilling are diverse. Small to moderate supplies seem to be available at shallow depths and in the eastern part where the gravel does not cover the limestone too deeply. Well 603 was drilled 206 feet into limestone and delivered only 1 gallon a minute. Well 599 was one of the few drilled into shale without success. If the presence of two unsuccessful wells out of five has any general meaning, the possibility of dry wells must be considered by prospective water users in this area. Records indicate that in the shale tract in the western part of this area the water level stands in idle wells less than 30 feet below ground. To the east it is almost certain that the water lies deeper except in valley bottoms.

Records of wells are fairly numerous in the area about Fishersville, and Waynesboro, southwest to Stuarts Draft. Shale and limestone form the bedrock, overlain in the eastern part by Pleistocene (?) gravel. In this area, 17 wells furnish the basis of the discussion of the ground water available to drilled wells, and some of the features of the geology

encountered in drilling. Many of the wells in this area are of average depth for limestone wells, but a few may be classified as deep. If small or moderate supplies are desired the conditions in this area appear to be very favorable, for 10 of the 17 wells yield 15 gallons a minute or more. The three wells drilled on the property of the duPont Rayon Mills at Basic City (610, 611 and 612) are 592, 734, and 560 feet deep, and their yields were tested at the time of completion at 560, 520, and 680 gallons a minute. These wells are exceptional—of large diameter, carefully developed, and expensively equipped—but they seem to indicate that large supplies are obtainable in more places than would be suspected from the results of ordinary household wells in some regions. It is impossible to say whether or not there are many other places in the Shenandoah Valley where such large water supplies can be developed from wells, but a report on the ground water in the Valley would be misleading if it failed to recognize the possibility that large supplies are available if appropriate measures are taken to find and develop them. One well of the 17 (well 614) might be considered a failure, and well 589, although it yields 3 gallons a minute, is 240 feet deep and is a poor well. Elsewhere, even where the gravel is thick enough to be the main water-bearer, the wells in this area are good producers in terms of their depth. Several records indicate that at the time the wells were completed the water stood in some places 50 feet below ground, but in wells in the shale less than 10 to 20 feet.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

Augusta Springs.—Population, 50. A well owned by the Stillwater Worsted Co. supplies drinking water for workers at the mill and employees' homes. The well is slightly more than 100 feet deep and yields a maximum supply of 20 gallons a minute, but the average consumption is not over 15 gallons a minute, or 22,000 gallons a day. Another well on the property yields only 1 or 2 gallons a minute and is not used. A third well was being drilled in June, 1935, and at a depth of 160 feet yielded practically no water. The well water is pumped to an open 80,000-gallon reservoir and thence to an overhead tank. The water is chlorinated in the line between the reservoir and the tank.

Bridgewater.—Population, 951. Water from a warm spring about half a mile southwest of the town flows by gravity from a small concrete spring box into a circular brick open 80,000-gallon reservoir 3 feet away. Water is pumped from the reservoir to an elevated 80,000-gallon tank in the town, whence it is distributed by gravity. The average consumption is about 60,000 gallons a day. The water is chlorinated at the pump house.

Craigsville.—Population, 150. Water from three springs owned by Dr. J. B. Tuttle flows by gravity into the mains. One spring discharges into a 7,000-gallon intake basin 138 feet above the railroad, on a hillside a short distance southeast of the town. Another nearby discharges into a 3,000-gallon intake basin 58 feet above the railroad. The third spring discharges into a 2,000-gallon intake basin 120 feet above the railroad. The total discharge of the springs is about 22,000 gallons a day, which is adequate for the needs of the community. The water is not treated.

Fordwick.—Population, 620. A well 1,428 feet deep, owned by the Lehigh Portland Cement Co., furnishes drinking water to the town. The water is pumped at a rate of about 32 gallons a minute to a 10,000-gallon concrete underground reservoir. Thence it is pumped to three reservoirs, the largest of which has a capacity of 30,000 gallons, from which the water enters the distributing system by gravity.

Middlebrook.—Population, 370. Two small springs owned and operated by R. W. H. Mish furnish water to about 20 families. The nearest spring is three-quarters of a mile southeast of the town and the rest are about a quarter of a mile apart. Each spring has an open concrete basin. The water is piped directly to the mains and is not treated.

Staunton.—Population, 11,990. In 1926 a gravity system was installed in the headwaters of the North River, where a concrete impounding dam forms a 124,000,000-gallon reservoir. The water is conducted 15 miles by gravity, through a mile-long tunnel in Lookout Mountain, to a storage reservoir 2 miles northwest of the city. Up to 1926 two limestone springs in Gypsy Hill Park supplied 700,000 to 1,000,000 gallons a day. The water was pumped to a 2,500,000-gallon reservoir on City Hill. These reservoirs are kept full of the spring water for an emergency supply. In 1930 the Gypsy Hill Springs and another spring on the Middle River 5 miles west of the city were pumped. The waters are chlorinated both at the intake and in the city reservoirs.

Stuarts Draft.—Population, 448. A spring, 2 miles east of the town, owned and exploited by R. A. Blacker, supplies this community. At the source there is a brick and concrete spring house. The water passes by gravity into a circular concrete and brick reservoir 1½ miles from the town, about 10 feet in diameter and 10 feet deep. The water is chlorinated at the reservoir.

Verona.—Population, 125. Water from a limestone spring owned by W. T. Weller, on a hill 6,500 feet southwest of the middle of the town, is distributed by gravity to a number of houses. The spring is protected by a covered concrete housing. The water is piped a short

distance to a closed 60,000-gallon concrete reservoir, thence to the town. The water is chlorinated at intervals of 4 to 6 weeks.

Waynesboro.—Population, 6,226. Water from a spring about 3 miles south of the town is pumped to a 2,000,000-gallon covered reservoir half a mile south of the town by two centrifugal pumps having a capacity of 1,250 gallons a minute. The water passes by gravity to the distributing system from the reservoir, which is 200 feet above the town. The average consumption is about 1,000,000 gallons a day and the maximum about 1,250,000 gallons. A smaller concrete reservoir and a standpipe are used to some extent for storage. The water is chlorinated at the spring.

TABLE 20.—*Records of wells*

(All drilled

No.	Location	Owner or name	Driller	Date completed	Depth (feet)
500	1¾ miles east-southeast of West Augusta.	J. S. Pancake	William Dawson	1924	154
501	Deerfield	John Rivercomb	William Dawson		65
502	Deerfield	John McCall	William Dawson		35
503	Deerfield	Mrs. Hite	William Dawson		40
504	Marble Valley	Mrs. Carson	William Dawson	1917	136
505	2¼ miles north-northeast of Augusta Springs.	J. M. Crowley	William Dawson	1910	26
506	Augusta Springs	Montague Payne	W. H. Hicks		60
507	1 mile northwest of Craigsville	Miss Virginia Gordon	Mr. Gordon		30
508	1 mile northwest of Craigsville	Stillwater Worsted Co.	W. H. Hicks		450
509	½ mile north of Craigsville	Miss Elizabeth Hotchkiss	W. H. Hicks		850
510	Mount Solon	Mount Solon Creamery & Ice Plant.	J. T. Helbert		260
511	2 miles west of Parnassus	J. P. Zimmerman	William Dawson	1914	136
512	3½ miles west of Parnassus	S. L. Huffman	William Dawson	1910	117
513	2½ miles north-northwest of Churchville.	Miss E. M. Talliaferro	William Dawson	1910	136
514	2¼ miles north of Churchville	Charles Huff	William Dawson	1915	125
515	1½ miles north of Churchville	M. M. Collins	William Dawson	1932	132
516	Churchville	E. V. Stautmyre	William Dawson	1932	73
517	Churchville	Mr. Seig	William Dawson	1932	45
518	Churchville	H. Frye	William Dawson	1917	168
519	Churchville	Mr. Colow	William Dawson	1932	48
520	2¼ miles southwest of Churchville	Mr. Jordan	William Dawson	1920	185
521	2¼ miles south-southwest of Churchville.	H. H. Stover	William Dawson	1921	240
522	3 miles south-southwest of Churchville	A. E. Miller	William Dawson	1913	282
523	4 miles south of Churchville	F. L. Yount	William Dawson	1923	141
524	4¼ miles south of Churchville	Mr. McCray	William Dawson	1931	280
525	5¾ miles north-northeast of Middlebrook.	Senator W. E. East	William Dawson	1931	63
526	3½ miles north-northeast of Middlebrook.	William McComb	William Dawson	1909	30
527	3 miles north-northeast of Middlebrook	E. A. Demasters	William Dawson	1917	99
528	1½ miles northwest of Middlebrook	R. J. Baylor	William Dawson	1917	409
529	1¼ miles northwest of Middlebrook	H. B. Sprowl	William Dawson	1917	157
530	1¼ miles northwest of Middlebrook	H. B. Sprowl	William Dawson	1917	256
531	2 miles east-southeast of Middlebrook	J. P. Smiley & Sons	William Dawson	1910	148
532	Greenville	H. Campbell	William Dawson	1915	136
533	4 miles southwest of Greenville	J. E. Moore	W. H. Hicks	1932	72
534	4¾ miles southwest of Greenville	Mrs. D. R. Carson	William Dawson	1910	88
535	4 miles south-southwest of Greenville	R. R. Berry	W. H. Hicks	1932	47
536	5¼ miles southwest of Greenville	Richmond Dairy Co	William Dawson	1926	162
537	¾ mile northeast of Steeles Tavern	R. R. Berry	W. H. Hicks	1924	365
538	¾ mile northeast of Steeles Tavern	Dabney Ramsey	W. H. Hicks	1921	45
539	Steeles Tavern	F. P. Weller	Mr. Gardner	1930	38
540	8 miles north-northwest of Staunton	F. G. Rust	William Dawson	1910	284
541	7½ miles north-northwest of Staunton	T. J. Crum	William Dawson	1932	205
542	4½ miles north-northwest of Staunton	Mr. Stockton	William Dawson	1920	165
543	4¼ miles north-northwest of Staunton	F. T. Dunlap	William Dawson	1913	157
544	5 miles north of Staunton	H. M. Spencer	William Dawson	1914	796
545	3¾ miles north of Staunton	J. F. White	William Dawson	1923	103
546	3 miles north of Staunton	Mrs. R. B. Sherrick	William Dawson	1913	152
547	3¼ miles north-northeast of Staunton	J. A. Walker	William Dawson	1909	112

in Augusta County, Virginia

wells)

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale	Brallier		10		Analysis on page 114.	500
Shale	Romney		6			501
Shale	Romney		5			502
Shale	Romney		Small.			503
Limestone	Helderberg		10			504
Shale	Romney		10			505
Shale	Romney	3	13			506
Shale	Brallier	Flowed	4		The well is not pumped. Flowed May 9, 1933. Analysis on page 114. Water had odor of H_2S.	507
Shale	Brallier	12	34			508
Shale	Romney	2	¼		10 gallons a minute encountered at 22 feet but cased off by order of the owner.	509
Limestone	Elbrook		50		Analysis on page 114.	510
Limestone	Elbrook		10		Analysis on page 114.	511
Limestone	Helderberg		20			512
Limestone	Stones River		3			513
Limestone	Elbrook		2			514
Limestone	Elbrook		10			515
Limestone	Conococheague		8			516
Limestone	Conococheague		10			517
Limestone	Conococheague		1½			518
Limestone	Conococheague		10			519
Limestone	Conococheague		10			520
Limestone	Conococheague		3		A mud-filled cavern was encountered at 140 feet, cased off. Water at 240 feet.	521
Limestone	Conococheague		8			522
Limestone	Conococheague		3			523
Limestone	Conococheague		4½			524
Limestone	Beekmantown		5		Well drilled 25 feet in bottom of 39-foot dug well.	525
Limestone	Conococheague	15	20			526
Limestone	Beekmantown		23			527
Limestone	Elbrook		6			528
Limestone	Conococheague		12			529
Limestone	Conococheague		10		Well situated on a hilltop.	530
Limestone	Beekmantown		1½			531
Limestone	Beekmantown		15			532
Limestone	Beekmantown	14	20			533
Limestone	Conococheague		2			534
Limestone	Beekmantown	8	23			535
Limestone	Beekmantown		20		Analysis on page 114.	536
Limestone	Conococheague	265	½			537
Limestone	Conococheague	16	13			538
Limestone	Conococheague		10	Very Small.		539
Limestone	Conococheague		5			540
Limestone	Conococheague		2			541
Shale	Athens		6			542
Limestone	Athens		12			543
Limestone	Athens		1½		Blasted later by owner and the yield said to have been increased.	544
Limestone	Beekmantown		5			545
Limestone	Beekmantown		5			546
Limestone	Beekmantown		20			547

TABLE 20.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Depth (feet)
548	2¾ miles north-northwest of Staunton	J. N. Jackson	William Dawson	1910	232
549	2½ miles north-northwest of Staunton	J. M. Heirs	William Dawson	1909	97
550	2½ miles north-northwest of Staunton	F. M. Somerville	William Dawson	1909	152
551	2½ miles north-northwest of Staunton	Mrs. J. A. Patton	William Dawson	1923	95
552	2¾ miles north-northwest of Staunton	Mrs. E. B. Sillings	William Dawson	1909	59
553	2½ miles north-northwest of Staunton	W. J. Mubray	William Dawson	1932	240
554	2½ miles north-northwest of Staunton	Mrs. T. C. Kinney	William Dawson	1909	191
555	3¼ miles northwest of Staunton	Ernest Dull	William Dawson	1926	119
556	3 miles east of Staunton	William McDaniels	William Dawson	1914	119
557	½ mile northeast of Staunton	C. R. Knowels	William Dawson	1910	199
558	½ mile north-northeast of Staunton	H. Diekes	William Dawson	1914	93
559	½ mile north of Staunton	A. A. Markley	William Dawson	1923	64
560	Staunton	Staunton Military Academy	H. N. Hulvey		1,400
561	Staunton	John Rutherford	William Dawson	1916	137
562	Staunton	National Cemetery	W. H. Hicks		350
563	Staunton	H. McK. Smith	William Dawson	1909	801
564	Staunton	Putnam Organ Co	William Dawson		689
565	Staunton	Beverley Garage	William Dawson	1923	250
566	Staunton	A. G. Fauver	William Dawson	1923	66
567	Staunton	William Sweet	William Dawson	1923	114
568	Staunton	Mrs. J. A. Rutherford	William Dawson	1928	175
569	Staunton	Mr. Cleveland	William Dawson	1926	98
570	3¾ miles west of Staunton	Reid Brothers	William Dawson	1928	216
571	3½ miles west of Staunton	Reid Brothers	William Dawson	1928	298
572	3¼ miles west of Staunton	Mr. Richel	William Dawson	1921	121
573	3¼ miles west of Staunton	E. D. Dundas	William Dawson	1917	326 536
574	2½ miles west of Staunton	E. W. Crosby	William Dawson	1909	188
575	2½ miles west of Staunton	P. H. Wilson	William Dawson	1909	162
576	2½ miles southeast of Staunton	W. J. Smith	William Dawson	1922	110
577	2¾ miles southeast of Staunton	Mr. Desper	William Dawson	1916	136
578	2 miles south of Staunton	M. Payne	William Dawson	1925	326
579	2¼ miles south of Staunton	J. A. Seaton	William Dawson	1924	125
580	2 miles south of Staunton	Oscar Downey	William Dawson	1931	180
581	3 miles west-southwest of Staunton	C. S. Yeago	William Dawson	1931	116
582	3¾ miles west-southwest of Staunton	J. F. Tannerhill	William Dawson	1909	245
583	3¼ miles southwest of Staunton	W. G. Gochenour	William Dawson	1924	264
584	3½ miles south-southwest of Staunton	J. H. Shaner	William Dawson	1931	320
585	4 miles south-southeast of Staunton	Hughert Irvine	William Dawson	1925	146
586	5 miles south of Staunton	H. M. Carter	William Dawson	1913	60
587	5 miles south of Staunton	Rev. C. Gilkerson	William Dawson	1914	125
588	5¾ miles southwest of Staunton	W. T. Harris	William Dawson	1922	136
589	6¼ miles south-southeast of Staunton	H. H. Stover	William Dawson	1921	240
590	Stuarts Draft	C. I. Kyte	William Dawson	1918	163
591	1¾ miles east of Stuarts Draft	Justice Cline	W. H. Hicks	1928	172
592	3½ miles northwest of Weyers Cave	Newton Crawn	H. N. Hulvey		127
593	Weyers Cave	Valley Creamery, Inc	H. N. Hulvey		179

Augusta County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Limestone..	Beekmantown.....	....	10½	....	Well at first was 132 feet deep, went dry, and was drilled to 232 feet. It was weakening again in 1932.	548
Limestone..	Conococheague....	....	20	....	....	549
Limestone..	Conococheague....	....	6	....	....	550
Limestone..	Conococheague....	....	3	....	....	551
Limestone..	Conococheague....	....	20	....	....	552
Limestone..	Conococheague....	....	8	....	....	553
Limestone..	Conococheague....	181	15	....	....	554
Limestone..	Beekmantown.....	....	5	....	....	555
Shale......	Martinsburg......	....	12	....	....	556
Limestone..	Conococheague....	....	12	....	....	557
Limestone..	Conococheague....	....	10	....	....	558
Limestone..	Conococheague....	....	15	....	....	559
Limestone..	Beekmantown.....	....	40	150	40-foot opening encountered at 600 feet but contained no water. Most of water came in below 600 feet. Well 8 inches in diameter.	560
Limestone..	Beekmantown.....	....	12	....	....	561
Limestone..	Beekmantown.....	80	⅕	....	Clay to 35 feet, but nearby unsuccessfull wells encountered it as deep as 120 feet.	562
Limestone..	Beekmantown.....	24	140	....	6 gallons a minute obtained at 75 feet; no more above 790 feet. Water used for ice making. Test lasted 24 hours.	563
Limestone..	Beekmantown Conococheague.	....	20	....	....	564
Limestone..	Beekmantown.....	....	30	....	Analysis on page 114. Water used for washing.	565
Limestone..	Beekmantown.....	....	20	....	....	566
Limestone..	Beekmantown.....	....	15	....	....	567
Limestone..	Beekmantown.....	....	15	....	....	568
Limestone..	Beekmantown.....	....	2	....	....	569
Limestone..	Beekmantown.....	....	20	....	....	570
Limestone..	Conococheague....	....	10	....	....	571
Limestone..	Elbrook..........	....	2	....	....	572
Limestone..	Elbrook..........	....	1½ 6½	....	Limestone was very hard. The well was drilled 210 feet deeper, and the yield was increased by 5 gallons a minute.	573
Limestone..	Conococheague....	....	10	....	Well originally was 137 feet deep, yielding 20 gallons a minute, but went dry and was drilled to present depth.	574
Limestone..	Beekmantown.....	....	10	....	....	575
Shale......	Martinsburg......	....	10	....	....	576
Shale......	Martinsburg......	....	10	....	....	577
Limestone..	Beekmantown.....	....	3½	....	....	578
Limestone..	Stones River......	....	15	....	....	579
Limestone..	Beekmantown.....	....	2½	....	....	580
Limestone..	Beekmantown.....	....	2½	....	The limestone was described by the driller as bouldery, seamy, and muddy.	581
Limestone..	Conococheague....	....	1	....	....	582
Limestone..	Conococheague....	....	3	....	....	583
Limestone..	Beekmantown.....	....	3½	....	....	584
Shale......	Martinsburg......	....	3	....	....	585
Shale......	Martinsburg......	....	5	....	....	586
Shale......	Martinsburg......	....	12	....	....	587
Limestone..	Conococheague....	....	1½	....	....	588
Limestone..	Athens..........	....	3	....	Mud-filled cavity at 140 feet; cased off.	589
Limestone..	Elbrook..........	....	15	....	Analysis on page 114.	590
Limestone..	Elbrook..........	20	3	....	....	591
Limestone..	Beekmantown.....	....	4	....	Water came in at bottom of the well.	592
Shale.......	Athens..........	....	30	....	Analysis on page 114.	593

TABLE 20.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Depth (feet)
594	Weyers Cave	King Colla Bottling Works	H. N. Hulvey	....	50
595	Weyers Cave	Farmers Milling Co	H. N. Hulvey	....	73
596	Weyers Cave	E. F. Carpenter	William Dawson	1932	108
597	1 mile east of Weyers Cave	Silas Morris	H. N. Hulvey	....	70
598	4½ miles southeast of Weyers Cave	Grottoes Cavern Co	William Dawson	1926	65
599	2¼ miles south-southeast of Weyers Cave	W. G. Flory	H. N. Hulvey	....	155 46
600	Fort Defiance	Augusta Military Academy	William Dawson	1926	290
601	¾ mile north-northeast of New Hope	Mr. Patterson	W. J. Gochenour	....	81
602	New Hope	T. Hunter	W. J. Gochenour	....	85
603	1¼ miles south-southeast of New Hope	W. E. Cline	William Dawson	....	206
604	5¼ miles north of Fishersville	Robert Myers	H. N. Hulvey	....	48
605	Fishersville	F. M. Carry	William Dawson	1914	68
606	Fishersville	Mr. Gilkerson	William Dawson	1920	125
607	1¼ miles southwest of Fishersville	C. C. Weller	William Dawson	1909	69
608	1¾ miles southwest of Fishersville	Dr. H. F. White	William Dawson	1923	120
609	Waynesboro	Richmond Dairy Co	W. H. Hicks	1922	325
610	Basic City	duPont Rayon Co	Virginia Machinery & Well Co.	....	592
611	Basic City	duPont Rayon Co	Virginia Machinery & Well Co.	....	734
612	Basic City	duPont Rayon Co	Virginia Machinery & Well Co.	....	560
613	3 miles south of Fishersville	W. H. Hicks	W. H. Hicks	1925	100
614	3 miles south of Fishersville	W. D. Hensley	W. H. Hicks	1900	130
615	4 miles south-southwest of Fishersville	William Driver	W. H. Hicks	1924	155
616	4½ miles south-southeast of Fishersville	T. O. Tinch	W. H. Hicks	1920	198
617	4½ miles south-southeast of Fishersville	Guy Wilson	W. H. Hicks	1924	100
618	6¾ miles south of Fishersville	J. E. Jackson	W. H. Hicks	1932	177

Augusta County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield when drilled (gallons a minute)	Draw-down (feet)	Remarks	No.
Shale......	Athens...........	....	2	....	This well was 30 feet away from well 593 and dried up when that well was pumped.	594
Limestone..	Stones River......	....	7	....	....	595
Shale......	Athens...........	....	10	....	....	596
Shale......	Martinsburg......	....	3	....	....	597
Limestone..	Conococheague....	....	20	....	Limestone overlain by ocher, sand, and gravel.	598
Shale......	Martinsburg......	....	0 ½	....	2 wells 150 yards apart.	599
Limestone..	Beekmantown.....	....	10	....	....	600
Shale......	Martinsburg......	....	16	Very small.	Well cased to 8½ feet.	601
Shale......	Athens...........	....	6	....	Well cased to 27 feet.	602
Limestone..	Beekmantown.....	....	1	....	....	603
Shale......	Martinsburg......	....	3	....	Analysis on page 114.	604
Limestone..	Beekmantown.....	....	16	....	Analysis on page 114.	605
Limestone..	Beekmantown.....	....	3	....	....	606
Shale......	Athens...........	25	20	....	....	607
Shale......	Martinsburg......	....	3	....	Analysis on page 114.	608
Limestone, white sandstone.	Waynesboro......	4	23	....	Analysis on page 114.	609
Dolomite...	Tomstown.......	....	560	27	Well 1. When this well is pumped a large spring nearby is weakened. Well is on flat ground at foot of Blue Ridge; 1,300 feet above sea level; 12 inches in diameter.	610
Dolomite...	Tomstown.......	....	520	13 when well is pumped at 350 gallons a minute.	Well 2. On flat ground at foot of Blue Ridge; 1,300 feet above sea level; 10 inches in diameter to a depth of 554 feet and 8 inches to bottom. Cased to 734 feet.	611
Dolomite...	Tomstown.......	Flows....	680	....	Well 5. This well is said to be lowered 15 feet when well 2 is pumped 350 gallons a minute. Analysis on page 114.	612
Limestone..	Elbrook..........	40	25	....	....	613
Limestone..	Elbrook..........	....	¼	....	....	614
Limestone..	Conococheague....	....	13	....	....	615
Limestone..	Waynesboro......	12	16	....	Some water at 18 feet in sand, rest in top of limestone.	616
Sand, gravel and ocher.	Pleistocene (?)....	60	5	....	....	617
Limestone..	Waynesboro......	14	20	....	Boulders, ocher, gravel, and sand overlying bedrock.	618

TABLE 21.—*Analyses of ground waters from Augusta County, Virginia*

(Analyst, E. W. Lohr. Parts per million. Numbers at heads of columns refer to corresponding well numbers in preceding table.)

	500	507	510	511	536	565	590	593	604	605	608	609	612
Silica (SiO_2)	14	....	....	....	....	....	....	68	....	....	....	....	9.2
Iron (Fe)	.01	....	....	2.4	....	....	....	.02	[4] 31	1.2	0.98	1.3	.01
Calcium (Ca)	5.1	[1] 26	86	75	87	87	[1] 32	122	[1] 35	[1] 45	96	[1] 40	13
Magnesium (Mg)	1.7	....	50	24	17	37	....	24	....	....	13	....	7.3
Sodium (Na)	51	[2] 9.7	[2] 17	[2] 5.7	[2] 15	[2] 7.5	[2] 4.0	21	[2] 6.0	[2] 12	[2] 2.5	[2] 1.3	.7
Potassium (K)	.8							1.0					1.3
Bicarbonate (HCO_3)	154	108	354	286	280	370	174	270	156	198	312	240	74
Sulphate (SO_4)	2.0	[1] 30	53	[1] 14	[1] 32	[1] 36	[1] 2	58	35	[1] 32	29	[1] 40	2.0
Chloride (Cl)	1.9	.9	60	8.0	18	21	.8	70	1.2	4.0	6.0	1.0	.8
Nitrate (NO_3)	.0	.10	34	47	38	19	1.1	84	.0	21	5.0	.10	.70
Total dissolved solids (calculated)	[3] 153	....	474	315	345	390	150	[3] 649	....	....	305	258	[3] 64
Total hardness as $CaCO_3$ (calculated)	20	[3] 100	420	286	287	369	[3] 138	403	[3] 153	[3] 192	293	[3] 237	62
Date of collection (1933)	May 9	May 9	May 9	May 9	May 9	May 9	May 9	May 9	May 8	May 9	ay 8	May 9	May 8

[1] By turbidity.
[2] Calculated.
[3] Determined.
[4] Turbid with precipitated iron when collected.

ROCKBRIDGE COUNTY

GENERAL FEATURES

Rockbridge County has an area of 616 square miles. Its population in 1930 was 20,902. Buena Vista is the largest community, with 4,002 inhabitants, but Lexington is nearly as large, with 3,752. Most of the residents are engaged in agriculture, and about two-thirds of the county is classified as farm land. Rockbridge County is not highly industrialized compared to other counties in the area, for there were in 1929 only 44 industrial establishments, employing a total of 979 workers. The value of the output during that year was $6,661,902.

Rockbridge County occupies a part of the Shenandoah Valley that is rather difficult to divide into provinces. The relief in the central and eastern parts of the county is somewhat greater than is typical of the parts of the valley to the northeast, and there is no sharp division between the Shenandoah Valley and the area that corresponds in other counties to the intermontane valleys west of North Mountain. However, in Rockbridge County the ridges are higher and steeper toward the west and northwest, and the area is cut up into small valleys. Rockbridge County is in the James River Basin, being drained by the North and South Rivers.

GEOLOGY

The Pulaski fault, which continues southwestward along the trend of the axis of the Massanutten syncline, is the major structural feature in Rockbridge County. East of the fault the pre-Cambrian rocks are overlain by the Cambrian basal quartzites. These quartzites crop out along the west front of the Blue Ridge and are spectacularly exposed in the gorge of the James River near Glasgow. Tomstown dolomite, Waynesboro formation, Elbrook limestone, and Conococheague limestone, dipping northwestward, crop out successively toward the northwest. These formations are involved in a synclinal fold whose axis is occupied by limestones of Beekmantown age. (The Chepultepec limestone, which occupies the axis in the southwestern part of the fold, has not been differentiated from the overlying Beekmantown in this report because it crops out only in the southwestern part of the area studied.) The succession of outcropping formations in the northwestern limb of the fold is interrupted by the Pulaski fault.

About 4 to 5 miles west-northwest of the Pulaski fault, and parallel to it, there is a system of en échelon faults cutting the rocks in a rather unsystematic pattern. The rocks between this system and the Pulaski fault represent a syncline whose axial region has been overridden by the Pulaski overthrust sheet. East and south of Lexington a small part of

the syncline is exposed, showing an interrupted outcrop of Martinsburg shale. The western limb of this syncline is cut by en échelon faults. Most of the rocks between the échelon faults and the Pulaski fault are Cambrian and Ordovician limestones; the oldest rocks crop out to the northwest. They dip chiefly southeastward. A small but intensely folded syncline is developed on a larger fold, and its axial region is occupied by the southwestern equivalent of the Romney shale. The axis of the fold lies about midway between Natural Bridge and the Rapps Mountains. About 4 miles west of Lexington the rocks are arranged in a dome-shaped anticline, which exposes Conococheague limestone at the core. This dome is in direct line with the axis of the small syncline just described. In general the area between the Pulaski fault and the échelon faults has a rather indefinite structural pattern.

There are three structural units in the area west of the en échelon faults—a plunging syncline at the northeast end, an intense synclinal fold on the northwestern border of the county, and an indefinite anticlinal fold at the southwest end. The syncline at the northeast end is irregular in form and not very tightly folded. Brallier shale occupies much of the axis, and Romney shale is widely exposed, but Tuscarora quartzite and Clinton formation cover much of the periphery of the fold, outcropping over an exceptionally large area. This syncline, which plunges northeastward, extends to the southwest corner of the county with Martinsburg shale at its axis. The axis of the second syncline passes between Goshen and Panther Gap, and Brallier shale occupies the central area. The folding in this syncline opens toward the northeast and closes outside of the county, southwest of Rockbridge Alum Springs. The anticline in the southwest corner of the county is feebly developed and is partly an expression of the plunge of the syncline near Goshen Pass, but it brings Cambrian and Ordovician limestones up to the surface in a terrane underlain mostly by Martinsburg shale.

GROUND-WATER CONDITIONS

The ground-water conditions in Rockbridge County must be discussed in a different manner from those in the other counties. Drilled wells are not numerous, and they were drilled so long ago that the owners and drillers have forgotten their detailed characteristics. In addition a large proportion of the rural inhabitants of Rockbridge County depend for their water supplies upon springs and cisterns. As a result very few complete records of wells are available. The field information was obtained by interviewing people at many of the communities in regard to individual water supplies and general conditions in the vicinity. As a result of this method of obtaining the data, it is believed that the discussion of ground-water conditions in the county can best be described

by considering in turn each community or other point where information was obtained.

Springs.—Springs are of more economic importance in Rockbridge County than in the other counties in the area studied, and more information was obtained regarding them. The springs in the Shenandoah Valley have been studied in greater detail by Reeves and others,[11] and the results systematically tabulated. In preparing the present report attention was confined, in other counties than Rockbridge, to drilled wells, the reports cited being relied on to furnish information concerning springs. In the description of Rockbridge County some information on springs gathered by the writer and some by Reeves is included, but for more detailed and comprehensive records the reader is referred to the bulletins above cited.

Goshen.—About 1 mile northwest of Goshen Big Spring rises from the valley fill and discharges into Mill Creek. The two main points of issue are seeps around which concrete basins roofed with wood have been erected. The combined flow of the two seeps was estimated about 10 gallons a minute in September, 1933. The water tastes slightly of iron, indicating an immediate origin in the Brallier shale, rather than a long passage through the fill in the valley. The spring was not used in 1933, but it was being considered as a possible source of public water supply for the village of Goshen. The springs, though small in discharge, were reported to be very reliable. South of Goshen and east of Goshen there are some large springs, and Reeves' report[12] includes the description of some springs nearer Buffalo Gap (Nos. 403, 404, and 405).

Wells in Goshen are fairly numerous, but most of them are dug or bored by hand and are about 20 feet deep. The town is on one side of a broad valley underlain by Brallier shale, upon which 10 to 20 feet of alluvium has been deposited. Water is easily accessible to dug and hand-bored wells, but in dry seasons many of them fail. Aside from the unreliability of some of these shallow wells, the whole system of obtaining water in a thin water-bearing bed into which waste water is discharged through cesspools and septic tanks is questionable hygienically. Furthermore, if the wells are put down to the bedrock in an effort to minimize the danger of their failing during droughts, the water is increasingly charged with iron at deeper horizons in the alluvium.

Records of two drilled wells (700 and 701) are set forth in the well tables. They indicate that water can be found in the shale in small

[11] Collins, W. D., Foster, M. D., Reeves, Frank, and Meacham, R. P., Springs of Virginia: State Comm. Cons. and Devel., Div. Water Resources and Power Bull. 1, 55 pp., map and tables, 1930.

Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, 56 pp., map and tables, 1932.

[12] State Commission on Conservation and Development, Division Water Resources and Power, Bull. 1, p. 42, 1930.

quantities at comparatively slight depth. However, the fact that the yield of both of these wells weakened in 1930 indicates that considerable water is taken from the alluvium, and hence these wells are not true indicators of the water-bearing properties of the bedrock. Apparently the shale in the immediate vicinity of the village is not promising as a source of even moderately large supplies. Static levels of the water in the wells are from 3 to 5 feet below ground.

Rockbridge Alum Springs.—The spring at Rockbridge Alum Springs is described by Reeves in the report on "Springs of Virginia,"[13] as spring 394. In the community known as "California," a mile east of the spring, a few wells have been dug into the alluvium with satisfactory results, and one well was drilled to a depth of 60 feet. Most of the people in this vicinity and down the valley to Goshen use the numerous small springs that issue from the hillsides. The water is said to be soft. Many of these springs fail in exceptionally dry summers, but a few of them are reported to be reliable. They weakened in the summer of 1932 but recovered by July, 1933.

Between Kerrs Creek and Rockbridge Alum Springs there are a few wells. Well 704 is typical of others in the vicinity—shallow and of moderate yield. The only deep well in this vicinity is 180 feet deep. Springs are small, the water is limy and hard, and most of them are reliable.

Collierstown.—At Alpin, 3½ miles north-northwest of Collierstown, a few very shallow wells (for example, well 705) have been put down into limestone. All but one of these wells deliver water at a very slow rate and are between 35 and 60 feet deep. North of this point small springs are used extensively by the inhabitants. Spring 11 is typical of the smaller springs in the shale areas, flowing at a rate of 3 or 4 gallons a minute. Other springs in this neighborhood are described in Reeves' report[14] (386 to 390). Many of these springs are large. Well 706 is one of the very few drilled wells in and near Collierstown. It is 60 feet deep and yields water at a moderate rate (probably small for limestone). A 29-foot dug well on the same property never fails but water level goes lower in droughts. Dug wells are fairly numerous in this vicinity and are shallow and fairly reliable. Many of the inhabitants use cisterns, and others use springs. Well 707 is a dug well typical of others in the area south of Collierstown.

Rapps Mill.—In the valley north of Rapps Mill wells are very scarce, most of the inhabitants using springs and cisterns. There are some large springs. (See Reeves' report,[15] springs 379-383.) Most of

[13] Op. cit., p. 41.
[14] Op. cit., pp. 40-41.
[15] Op. cit., p. 40.

the springs that are used are small but are reported to be reliable. Ayres Spring (Reeves' 383), north of Rapps Mill, flows from a cavern-like opening in a hillside. Its flow is so large that the city of Lexington pumped 2,500 to 3,000 gallons a day from it as an auxiliary supply during the drought of 1930-31.

Murat.—Springs are abundantly used in the vicinity of Murat, where there are many small springs, and a few large ones, such as Reeves' 391 and 392. A smaller spring than these, but larger than many of the household springs, issues on the property of W. A. Gordon in Murat. It flows over 100 gallons a minute and furnishes enough water for four families. It is reported never to have dried up, and its long use is proved by a spring house that has for many years stood over it at its point of issuance.

Natural Bridge.—At Longwood, 4 miles north of Natural Bridge, a few moderately large springs and many small ones that issue from the limestone are used for household supplies. Most of these springs are reported to maintain their flow during dry years, especially the larger ones. Wells are not numerous, but many of the inhabitants use rain-water cisterns.

At 4½ miles north of Natural Bridge well 709 has been drilled on the property of Mr. Cummings. It is the only well in the vicinity for which information was available and may not truly represent the ground-water conditions in that part of the county, but its yield is larger with respect to its depth than that of many of the other wells in Rockbridge County. It was drilled in the bottom of a 40-foot dug well that had failed. Between Longwood and Natural Bridge drilled wells are somewhat more numerous, but they yield less water than well 709. Well 710 is less than 60 feet deep but yields only 3 gallons a minute. One well nearby is about as deep but delivers less water. Two other wells are deeper—100 and 190 feet; one of them yields a little water, the other a comparatively large amount. Here, as in other nearby localities, drilled wells are relatively scarce, but springs and cisterns are abundant.

The hotel at Natural Bridge is supplied by the Barger and Claytor springs. The Barger Spring issues from a limestone ledge at the foot of a hill northwest of the hotel, through a single cavernous opening. The water discharges into a concrete basin 10 by 12 feet, where it is piped into a line and carried by gravity to the hotel. During the peak season 40,000 gallons a day is used without stopping the spring from overflowing, although both springs weaken somewhat in dry seasons. The water is hard. Claytor Spring is similar to Barger Spring except that its flow is greater and it fluctuates less from season to season and

from year to year. Reeves' report[16] contains information about one spring near Natural Bridge (384).

At Natural Bridge Station several wells have been drilled to moderate depth. Well 711 is 121 feet deep and yields over 20 gallons a minute, which is the capacity of the pump. Other wells are of comparable depth but do not yield so much water. Most of the inhabitants in the vicinity use springs, which are numerous.

Bells Valley.—Bells Valley is underlain by Romney shale. The soil is thin and consequently the dug wells upon which many of the inhabitants depend for their water supplies are only moderately satisfactory. They can go only 15 feet or slightly deeper (see well 712) before reaching bedrock, their yield is small, and during droughts they go dry. Unfortunately springs are few, and the one or two in the vicinity that are conveniently enough located to be used are small. According to the available records, the ground-water conditions are similar for at least 3¾ miles to the south, for well 713 is also a shallow dug well, with "plenty" of water for a bucket pump of chain type. In the summer of 1933 the water level in this well was only 6 feet above the bottom of the well as it was originally dug, but the owner says that it has never failed. Nearby wells are shallow dug wells. It is reported that if wells are carried down too near the bedrock (Romney shale) the water is highly charged with iron. Only one household in the vicinity depends on a spring for water supply.

Jump.—In the vicinity of Jump the chief source of ground water consists of springs. They are mostly small, such as the one on the property of Nash Miller, which flows at a rate of 1 to 3 gallons a minute. At least some of them failed in 1930, and others were weakened to a greater or lesser extent, in spite of the fact that limestone crops out in that area. Many of the inhabitants use rain cisterns for their entire household supplies.

Rockbridge Baths.—The Rockbridge Baths locality is interesting in that thermal springs issue from limestone on the east limb of a syncline.[17] They discharge where the North River has cut into the limestone. Analyses of the water of several of the springs show that the water is relatively high in dissolved minerals,[18] and the water is thermal, the temperature of some of the waters being as high as 70° F. The flow of the springs is moderate to small, 600 gallons a minute being the flow of the largest spring measured there.

[16] Op. cit., p. 40.

[17] Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36 p. 49, 1932.

[18] State Commission on Conservation and Development, Div. Water Resources and Power Bull. 1, p. 43, 1930.

It is the conclusion of those who have studied the geologic occurrence of thermal springs that the water is carried by artesian pressure down the dip of synclinal beds and up to their point of discharge on the opposite limb. The temperature of the water as it emerges represents the comparatively high temperature of the rocks beneath the axis of the syncline. Most of the thermal springs are relatively high in dissolved mineral matter. This system of artesian flow is impelled by gravity, and the water derived from precipitation must enter the water-bearing bed on one limb of the syncline at a higher altitude than the point on the opposite limb where it discharges as a spring.

Rockbridge Baths is a summer colony, and some of the springs are protected by bath houses and piped into bathing pools. Most of them are owned privately. Farmers outside of the community depend mostly on small springs for their water supplies. All the springs in the vicinity were weakened during the dry years of 1930 and 1931, but few, if any, failed. A few dug wells of shallow depth are used in the vicinity. They are reported to yield small but reliable supplies of water.

Timber Ridge.—One spring owned by C. N. McGuffin supplies several of the houses in the small community of Timber Ridge. The flow is small, but the seasonal and yearly fluctuations are not great. The water, originating in limestone, is rather hard. All the inhabitants of nearby homes and farms use either springs or cisterns. There are no wells.

Lexington.—About 5 miles north of Lexington several dug wells supply the inhabitants with small quantities of water. (See well 714.) The well on the property of F. G. Berry is 32 feet deep, dug into alluvium. Its yield is ordinarily sufficient for the needs of the household, but it failed in 1930. There are few springs between this point and Rockbridge Baths, and dug wells are commonly used.

Springs in the vicinity of Lexington are described by Reeves.[19] Spring 400 is a pond 7 acres in extent, fed by several springs that bubble up from the bottom and enter from the sides. Its flow was measured by Reeves at 4,500 gallons a minute. Part of its outflow is conducted by a flume to a mill and used for water power. The range of the water level in the pond from year to year is said to be no more than 6 inches.

Several wells have been drilled in recent years in Lexington and a few miles to the south and west. Fairly complete records of seven of these wells are available. They range in depth from 26 to 511 feet and yield from 40 gallons a minute to nothing. Two wells of moderate to slight depth yield 40 and 35 gallons a minute respectively, the others

[19] Op. cit., p. 41.

yield 6 gallons a minute or less, and the two deepest wells are unsuccessful. The yield of the seven wells averages only 12 gallons a minute. The records of these wells indicate that all the uncertainties inherent in obtaining water from wells in limestone are exaggerated in the vicinity of Lexington. The reason is probably to be found in the geomorphic history and development of the region rather than in any peculiar characteristics of the limestone, although the specific set of circumstances is as yet unknown. The records of these wells may be interpreted either optimistically or pessimistically by a prospective seeker of a ground-water supply, and either view has justification. The writer would hesitate to advise spending a large amount of money drilling deeply for water if none is encountered in the first 100 or 150 feet, because the two most productive wells in this vicinity are comparatively shallow. The static water level in the wells was at no greater depth than 30 feet when they were completed.

Raphine.—At Raphine springs are not abundant, and most of the inhabitants use cisterns. There is one shallow dug well in the community. Two springs side by side, owned by Mrs. F. E. Fulwider, supply three households. These springs are in a valley, and the water is pumped to a storage tank on a hill behind the houses. One spring has a tile casing driven into the basin where it issues. The other outlet is provided with a concrete basin, and the flow through the overflow pipe of this opening was estimated at about 50 gallons a minute. The springs are said never to fail.

Vesuvius.—In the vicinity of Vesuvius many of the small springs are used for household supplies, and in addition a few wells have been dug. Most of the wells are 10 to 15 feet deep and are situated in the valley of the South River. The water is said to be soft, but the spring water is harder. Well 723 is on the side of the valley and consequently deeper than most of the others. It is about 40 feet deep, ends in gravel, and delivers abundant water for the needs.

Brownsburg.—Near Brownsburg many springs are used. The springs are small, and many of them have gone dry in the more severe droughts, like the one of 1930. In addition to the springs nearly every household has a rain-water cistern. One spring half a mile south of Brownsburg, on the Rees property, supplies nine families in the village. The spring rises in a broad valley, from the limestone beneath, and is gathered in a concrete basin and piped to Brownsburg by gravity. The flow weakened a little in 1930-31 but did not fail. This spring has always overflowed, even when being drawn upon heavily, and in the late summer of 1933 it was estimated that 50 gallons a minute was passing out through the overflow pipe.

Fairfield.—Springs are used extensively in the vicinity of Fairfield, it being reported that every farm has one or more from which to draw water. One spring on the property of Thorne Barthwicke supplies several families, all of whom pipe and pump their own supplies from a basin excavated into the limestone. The flow was estimated at less than 10 gallons a minute. The drought of 1930-31 had little apparent effect upon the discharge of this spring. The nearby springs were reported to have withstood the drought, although some of them weakened.

Incomplete records of three drilled wells in this vicinity indicate that shallow wells put down in the limestone derive only a small supply of water. The wells were reported to be 22, 60, and 65 feet deep, and one yielded less than 3 gallons a minute; the yields of the others were characterized as "fair" and "strong."

There is an ebbing and flowing spring on the property of the Marlbrook Lime Co., 2 miles southeast of Fairfield. It flows about 500 gallons a minute and has a period of fluctuation of 7 minutes. It is said that the behavior of the spring is very regular.

Midvale.—In the vicinity of Midvale each household depends upon its own spring for water, except three—two having wells and one a cistern. Only one spring failed during drought. The well at the station master's house on the Norfolk & Western Railway (well 627) is 97 feet deep, and delivers a "very strong" supply from limestone.

Riverside.—Near Riverside, as in other parts of the county, springs are fairly numerous. The springs in the east side of the valley are small, but those that issue from the limestone on the west side are larger. Dug wells range in depth from 18 to nearly 100 feet. Many of them went dry in 1930-31. Well 728 is 30 feet deep, dug into clay and gravel, and is reported to have a "strong" yield.

Buena Vista.—No good records were available of wells in Buena Vista. Well 729 is reported by the engineer of the Blue Ridge Tannery to be 725 feet deep, but there was no record of its yield, rate of pumping, or depth to the static water level. Other industrial establishments use river water. At Mechanicsville, 3 miles southwest of Buena Vista (not shown on the map), large springs are abundant and widely used. They are reported to be reliable. Many of the inhabitants have cisterns for soft water.

Glasgow.—Five springs on the east slope of Sallings Mountain supply Glasgow with water. The springs issue immediately from valley wash, but the ultimate source is, partly at least, the near-surface part of the Tomstown dolomite. The springs are protected by concrete basins at their points of emergence, whence they are piped to a small concrete

storage reservoir down the slope of the mountain. From the reservoir the water is distributed to the consumers by gravity. The supply has been adequate at all times, although some seasonal fluctuation in their rate of flow is evident. Well 730 has been drilled between the springs and reservoir to provide an emergency supply. The hole is 360 feet deep. At the bottom a large cavity was entered, and water came within 8 feet of the surface. Pumping at 50 gallons a minute for 24 hours lowered the water level by only 11 feet.

Summary.—Springs are abundant and comparatively large in the parts of Rockbridge County underlain by limestone, especially where some topographic feature is present to intersect the water table. Such a feature is the valley of the South River. The springs are widely used in most areas for household supplies. In areas underlain by shale and sandstone and in certain localities underlain by limestone springs are few and small. In such places wells are depended upon to a moderate extent, and cisterns are widely used.

The county as a whole seems to hold out poor inducement to prospective seekers of water supplies from wells. However, the possibility of obtaining large well supplies at greater depth has not been adequately explored, and systematic drilling at great depth might be successful.

MUNICIPAL SUPPLIES DEPENDENT ON GROUND WATER

Buena Vista.—Population, 4,002. Two mountain streams supply most of the water. Water from Noel Run is collected in an open 360,000-gallon reservoir, and water from Indian Gap in a 60,000-gallon reservoir. Hall Spring, 1½ miles southwest of the town, is used as an auxiliary supply. The spring water is pumped by a Diesel 45-horsepower centrifugal pump directly into the mains but discharges by back pressure into the Noel Run reservoir. The spring flows about 500 gallons a minute, and a maximum of 250 gallons a minute can be pumped from it. In 1932 about 15,635,000 gallons was pumped from the spring; in 1933 about the same amount, but in 1934 only 915,000 gallons. The water of the surface supplies is chlorinated at the intakes. The spring water is chlorinated at the pump house.

Glasgow.—Population, 507. Five springs on Sallings Mountain, northwest of the town, provide part of the water for the publicly owned system. Each spring is equipped with a covered concrete shelter, and the water is piped from them to a concrete impounding reservoir down the mountain slope. From the reservoir the water is distributed by gravity. Between the springs and the reservoir a well was drilled to a depth of 360 feet in the winter of 1934-35. The well was pumped at a rate of 50 gallons a minute for 24 hours, and the draw-down was only 11 feet,

which will easily furnish the 20,000 gallons a day increases in consumption expected when the Blue Ridge Carpet Co. begins operation of a new plant in the town. The total capacity of the system is believed to be about 216,000 gallons a day.

Goshen.—Population, 200. The Stillwater Worsted Co. furnishes drinking water to its mill workers and to the company-owned homes of employees. The well is 83 feet deep and yields about 10 gallons a minute. It is pumped about 18 hours a day. The distribution is effected by a pressure tank.

TABLE 22.—*Records of wells*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Type	Depth (feet)
700	Goshen	Stillwater Worsted Co.	Mr. Gordon	1929	Valley floor.	Drilled.	83
701	Goshen	C. C. Carroll	Mr. Gordon		Valley floor.	Drilled.	68
702	Goshen	J. O. Humphrey			Valley floor.	Dug	12
703	1¾ miles east of Alum Springs.	E. F. Sellers			Valley floor near foot of mountain.	Dug	10
704	5 miles east-southeast of Rockbridge Alum Springs.	R. A. Engleman				Drilled.	40±
705	3½ miles north-northwest of Collierstown.	Earl Huffman				Drilled.	37
706	Collierstown	A. W. Morrison				Drilled.	60±
707	2¼ miles southwest of Collierstown..					Dug	60±
708	5 miles southwest of Collierstown.	Charles Leech				Drilled.	75
709	4½ miles north of Natural Bridge Station.	Mr. Cummings				Drilled.	119
710	5 miles northwest of Natural Bridge Station.	J. W. Miller	Mr. O'Connor, the younger.	1917		Drilled.	57½
711	Natural Bridge Station					Drilled.	121
712	Bells Valley	J. H. Ralston				Dug	15
713	3¾ miles south of Bells Valley.	J. L. McDonald				Dug	18
714	4¾ miles north of Lexington.	F. G. Berry				Dug	32
715	4¾ miles northwest of Lexington.	J. D. Fitzpatrick	W. H. Hicks			Drilled.	74
716	Lexington	Prof. Gillam	S. P. Totten			Drilled.	115
717	Lexington	William Agnor	S. P. Totten			Drilled.	85
718	Lexington	William Agnor	S. P. Totten			Drilled.	225
719	Lexington	Everett Tolley	S. P. Totten			Drilled.	511
720	1¾ miles south-southwest of Lexington.	R. S. Bruce Filling Station.	S. P. Totten			Drilled.	26
721	3¾ miles southwest of Lexington.	Col. Derbyshire	S. P. Totten			Drilled.	52
722	3 miles south-southwest of Lexington.	Jake Paggett	S. P. Totten			Drilled.	85
723	Vesuvius	Mrs. E. J. Bradley			Hillside	Dug	40+
724	Fairfield	E. O. Huffman		1910		Drilled.	22±

[1]When drilled.

in Rockbridge County, Virginia

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield: Gallons a minute	Yield: Date of measurement	Draw-down (feet)	Remarks	No.
Alluvium, shale.	Recent (?), Brallier.	5	10	When drilled.	....	Pumped about 18 hours a day. Well weakened in drought of 1930-31. Water used for drinking. 20 feet to top of bed.	700
Alluvium, shale.	Recent (?), Brallier.	3	6	When drilled.		Weakened somewhat in drought.	701
Alluvium...	Recent (?)........	7	....	....	....	Yield changes little from season to season.	702
Alluvium...	Recent (?)........	....	"Strong"	....	....	....	703
Limestone..	Martinsburg, lower part (?).	4	Large....	....	....	....	704
Limestone..	Conococheague....	....	Small....	....	....	....	705
Limestone..	Beekmantown.....	[1] 50±	Moderate.	....	....	....	706
Limestone..	Stones River......	30±	Enough for household uses.	....	....	....	707
Limestone..	Stones River......	....	....	....	....	....	708
Limestone..	Elbrook..........	[1] 35	10	....	Very small.	Drilled in bottom of 40-foot dug well. Depth to top of bed 40 feet.	709
Limestone..	Chambersburg....	....	3	....	....	Well cased to 17 feet.	710
Dolomite...	Tomstown........	....	20	....	Very small.	Earth-filled cavity several feet thick was passed through in drilling. Capacity of pump, 20 gallons a minute; motor pump.	711
Shale......	Romney..........	....	Small....	....	....	Failed in 1930.	712
Shale......	Romney..........	12	Sufficient.	....	....	Never fails in droughts. Strong in iron.	713
Gravel.....	Recent (?)........	20±	Good....	....	....	Failed in drought.	714
Limestone..	Conococheague....	18	....	....	....	Myers electrically driven deep-well pump.	715
Limestone..	Blount...........	[1] 20	35	When drilled.	75	Openings in limestone at 52 and 105 feet. Well 6 inches in diameter; cased to 14 feet.	716
Limestone..	Blount...........	[1] 25	2	When drilled.	80	Opening in limestone at 82 feet. Well 6 inches in diameter; cased to 18 feet.	717
Limestone..	Blount...........	....	0	....	....	2 gallons a minute encountered at 88 feet but lost the water while drilling deeper. Well 6 inches in diameter.	718
Limestone..	Blount...........	....	0	....	....	....	719
Limestone..	Blount...........	[1] 8	6	When drilled.	....	Water obtained at 16 feet. Well cased to 11± feet.	720
Limestone..	Blount...........	[1] 6	40	When drilled.	Very small	Water obtained at 35 feet. Well cased to 7 feet.	721
Limestone..	Chambersburg....	[1] 30	4	....	....	Water obtained at 75 feet. Limestone was massive above that depth. Well cased to 9 feet.	722
Gravel.....	Recent (?)........	40±	"Strong".	....	....	Not weakened by drought.	723
Limestone..	Conococheague....	....	Less than 3.	....	....	Limestone beds dip steeply, and driller's bit was deflected.	724

TABLE 22.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Topographic situation	Type	Depth (feet)
725	Fairfield	Z. W. Maphis		1910		Drilled.	60
726	Fairfield	John Winters			Flats	Drilled.	65
727	Midvale	Norfolk & Western Railway Co.			Valley	Drilled.	97
728	Riverside				Valley	Dug	30
729	Buena Vista	Blue Ridge Tannery			Valley	Drilled	725
730	Glasgow	Town of Glasgow			Valley	Drilled.	360

Rockbridge County, Virginia—Continued

Character of material	Geologic horizon	Depth to water level when drilled (feet)	Yield: Gallons a minute	Yield: Date of measurement	Drawdown (feet)	Remarks	No.
Limestone..	Conococheague....	45±	Fair.....	....	....	Well cased to 15 feet. Water never used.	725
Limestone..	Conococheague....	....	"Strong".	....	....	....	726
Gravel, limestone.	Recent (?) Elbrook.	....	"Very strong".	....	....	Did not fail in drought.	727
Clay and gravel.	Recent (?)........	20±	Strong...	....	....	....	728
Limestone..	Elbrook..........	....	....	....	....	Water used for industrial purposes.	729
Dolomite...	Tomstown........	8	50	Feb. 1935	11	18-inch cavity at bottom of hole. Small supply at 100 feet. Duration of test 24 hours. Municipal. 16 feet from top of bed.	730

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